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TRANSACTIONS

OF THE

AMERICAN CERAMIC SOCIETY

VOLUME XII

Containing Papers and Discussions Read at the Meeting Held at Pittsburgh, Pa., Feb. 7th, 8th and 9th, 1910, With Some Other Contributions.

This Society is not, as an organization, responsible for the statements of facts or opinion expressed in its papers and discussions.

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GRAHAM, W. A. P., New Brighton, Pa. — Secy. and Treas., American Porcelain Company.

GREENER, GEO. COURTRIGHT, E. M., (in Cer.) N. Bennett St., Boston, Mass. — Instructor in North Bennett St. Industrial School.

GREGORI, JOHN N., Chicago, Ill. — Kiln Burner, North Western Terra Cotta Co.

GREGORY, M. E., Corning, N. Y. — Prop., Corning Brick, Terra Cotta & Tile Company.

GRIFFIN, CARL H., Worcester, Mass. — Asst. Supt., The Norton Company.

GRUEBY, WILLIAM H., Boston, Mass. — Pres., Gen. Mgr., Grueby Faience Company.

GUASTAVINO, RAFAEL, JR., The Fuller Bldg., 949 Broadway, New York City. — Pres., The R. Guastavino Company.

HALL, ROBERT T., East Liverpool, Ohio. — Secy. and Treas., Hall-Meakin Clay Company.

HAMILTON, JAMES, Trenton, N. J. — Supt., Ideal Pottery of Trenton Potteries Company.

HANSEN, ABEL, Fords, N. J. — Prop. and Mgr., Fords Terra Cotta & S. Works.

HARDY, ISAAC ERNEST, Momence, Ill. — Supt., Tiffany Enameled Brick Co.

HARE, ROBERT L., Fort Worth, Texas. — Cobb Brick Company.

HARKER, H. N., East Liverpool, Ohio. — Gen. Mgr., Harker Pottery Company.

HARPER, JOHN LYALL, Niagara Falls, N. Y. — Chief Engineer, Niagara Falls Hydraulic Power & Manufacturing Company.

HARRIS, CHARLES T., Flatiron Bldg., New York City. — N. Y. Mgr. Fiske & Co., Inc.

HASBURG, JOHN W., 244 Lincoln Ave., Chicago, Ill. — Pres., John W. Hasburg Company (Inc.).

HASSLACHER, JACOB, 100 William St., New York City. — Pres., The Roessler & Hasslacher Chemical Company.

HASTINGS, FRANCIS N., Hartford, Ct. — Hartford Faience Company.

HAVILAND, PAUL B., 45 Barclay St., New York City. — Haviland & Company.

HAYNES, FRANK R., Baltimore, Md.	Managing Partner, D. F. Haynes & Son.
HENDERSON, H. B., B. Sc., 1538 N. High St., Columbus, Ohio.	Supt., Pyrometric Cone Factory.
HEROLD, JOHN J., Golden, Colorado.	
HIGGINS, ALDUS C., Worcester, Mass.	Mgr., Electric Furnace Plant, Norton Company.
HINE, HOMER H., Wellsville, Ohio.	Supt., McLain Fire Brick Company.
HIPP, RALPH T., 4600 S. Kingshighway, St. Louis, Mo.	Ceramist, Laclede-Christy Clay Products Company.
HIPP, WM. G., Massillon, Ohio.	Secy. and Gen. Mgr. Massillon Stone and Fire Brick Company.
HITCHINS, E. S., Olive Hill, Ky.	President, Olive Hill Fire Brick Company.
HOLLAND, W. W., 1122 Madison Ave., Baltimore, Md.	Research Asst. in Chemistry, Johns Hopkins Chemical Dept.
HOPLER, THORNTON M., Palo Alto, Calif.	Student, Leland Stanford, Jr., University.
HULL, W. S., Jackson, Miss.	Architect.
HUMPHREY, DWIGHT ELMER, Cleveland, Ohio.	Deckman-Duty Brick Company.
HURSH, RALPH KENT, 325 Fisk St., Pittsburgh, Pa.	Junior Ceramic Chemist, U. S. Geol. Survey.
JACQUART, BERNARD, South River, N. J.	Supt., American Encaustic Brick and Tile Company.
JEPPSON, GEORGE N., 286 W. Boyleston St., Worcester, Mass.	Asst. Supt., Norton Company.
JUNGE, WILLIAM H., Glenview, Ill.	Northwestern Terra Cotta Company.
JUSTICE, ITHAMAR M., 3305 E. Third St., Dayton, Ohio.	Head of Engineering Department, C. W. Raymond Company.
KANENGEISER, FRED. R., Bessemer, Pa.	Gen. Supt., Bessemer Limestone Company.
KEELER, R. B., 918 W. Illinois St., Urbana, Ill.	
KENDRICK, J. LUCIUS S., Johnsonburg, Pa.	Supt., Johnsonburg Vitrified Brick Company.
KERR, CHARLES HENRY, Southbridge, Mass.	Research Chemist, American Optical Company.
KNOTE, JOHN H., M. Sc., Urbana, Ill.	Assistant Professor in Ceramics, University of Illinois.
KOCH, CHARLES FREDERICK, 2407 Highland Ave., Mt. Auburn, Cincinnati, Ohio.	Cambridge Tile Mfg. Company.

KOCH, JULIUS J., 3325 Caroline St., St. Louis, Mo.	
KOCH, WILLIAM H., Wheeling Ave., Zanesville, Ohio.	Superintendent Art Pottery.
KRICK, GEO. M., Decatur, Ind.	Gen. Mgr., Krick, Tyndall & Company.
LAMBIE, JAMES M., Washington, Pa.	Vice Pres. and Asst. Gen. Mgr., Findlay Clay Pot Co.
LANDERS, WILLIAM FRANKLIN, Indianapolis, Ind.	Supt., U. S. Encaustic Tile Works.
LANDRUM, ROBERT D., Lawrence, Kansas.	Asst. Prof. of Chemistry, University of Kansas.
LANSING, CHARLES W., 45 Plymouth Court, Chicago, Ill.	Editor "Brick."
LAWSHE, C. PERRIN, Trenton, N. J.	Gen. Mgr., Trent Tile Company.
LAYMAN FRANK E., E. M., (in Cer.) The Aberdeen, Milwaukee, Wis.	Chemist, Cuttler-Hammer Company.
LEWIS, EDWIN J., Chittenango, N. Y.	
LINDLEY, JACOB, Tiltonville, Ohio.	Riverside Potteries Company.
LINDSAY, ROBERT D., Denver, Colorado.	Supt., Denver Pressed Brick Co.
LLOYD, HARRY, New Salisbury, Ohio.	Supt. Colonial Clay & Coal Co.
LOCKE, FREDERICK M., Victor, N. Y.	Manufacturer Porcelain Insulators.
LOCKE, MORTON FIELD, Lima, N. Y.	Manufacturer Porcelain Insulators.
LOUTHAM, WM. B., East Liverpool, Ohio.	Mgr., Loutham Supply Co.
MCBEAN, ATHOLL, 311 Crocker Bldg., San Francisco, Cal.	Secy. Gladding, McBean & Co.
MCDOUGAL, TAINE G., 165 E. 15th Ave., Columbus, Ohio.	Student in Ceramic Engineering, Ohio State University.
MCELROY, ROY HARDEN, 1930 North Main St., Dayton, Ohio.	Ceramic Engineer, The C. W. Raymond Company.
MACFARLAND, WARREN C., Gallatin, Pa.	Engineer, Tempest Brick Co.
MCINTYRE, JOHN P., McKeesport, Pa.	Prop., McKeesport Brick Works.
MACMICHAEL, PAUL S., P. O. Box 777, Seattle, Wash.	President, Northern Clay Co.
MCNICOL, JOHN A., East Liverpool, Ohio.	Treasurer, D. E. McNicol Pottery Company.
MADDISON, ERNEST A., 2932 Howard St., San Francisco, California.	With Steiger Terra Cotta and Pottery Works, South San Francisco.

MADDOCK, ARCHIBALD M., Trenton, N. J.	Thomas Maddock & Sons.
MADDOCK, JOHN, Trenton, N. J.	John Maddock & Sons.
MALM, ARTHUR T., CR. E., 18 Orme St., Worcester, Mass.	Ceramic Engineer, Norton Co.
MALTBY, ALFRED, Corning, N. Y.	Supt., Corning Brick, Terra Cotta & Tile Co.
MANDLE, I., Wright Bldg., St. Louis, Mo.	Secy. and Treas., Mandle-Sant Clay Company.
MANDLE, SIDNEY, Wright Bldg., St. Louis, Mo.	Asst. Treas., The Mandle-Sant Clay Company.
MANDLER, CHARLES J., 2104 Franklin Ave., Toledo, Ohio.	Pres., The Allen Filter Co.
MANOR, JNO. M., East Liverpool, Ohio.	Mgr., The Golding Sons Company.
MASON, FORTUNATUS Q., East Liverpool, Ohio.	Color Manufacturer.
MAYER, ARTHUR ELLIS, Beaver Falls, Pa.	With Mayer Pottery Company, Ltd.
MEAKIN, ROBERT J., East Liverpool, Ohio.	Hall-Meakin Clay Co.
MELLOR, F. G., Trenton, N. J.	Gen. Mgr., Cook Pottery Company.
MERRY, CARL E., Streator, Ill.	Barr Clay Company.
METZNER, OTTO, 1019 Windsor St., W. H., Cincinnati, Ohio.	Supt. of Manufacture, Rookwood Pottery Company.
MIDDLETON, JEFFERSON, 3412 13th St., Washington, D. C.	Statistician, U. S. Geological Survey.
MILES, JAMES, 1072 Penn Ave., East End, East Liverpool, Ohio.	
MILLIGAN, FRANK W., Findlay, Ohio.	Pres. and Gen. Mgr., The United States Electric Porcelain Co.
MONTGOMERY, E. T., E. M. (in Cer.) 319 East 15th Ave., Columbus, O.	
MOORE, HERBERT W., Tottenville, N. Y.	Atlantic Terra Cotta Co.
MOREY, D. F., Ottumwa, Iowa.	Mgr., Ottumwa Press Brick & Coal Company.
MORRIS, WILLIAM C., St. Louis, Mo.	Pres., Laclede-Christy Clay Products Company.
MOSES, JAMES, Trenton, N. J.	Mercer Pottery Company.
MOULTON, D. A., Ironton, Ohio.	
MUNSHAW, LAMBERT M., North Crystal Lake, Ills.	Ceramist, American Terra Cotta & Ceramic Company.

MYERS, RALPH E., Bloomfield, N. J.	Ceramic Engineer, Westinghouse Lamp Company.
OGAN, MARK, Clayton, Wash.	Gen. Supt., Washington Brick, Lime and Sewer Pipe Co.
OGDEN, LESTER, 106 Price St., Columbus, Ohio.	Student in Ceramic Engineering, Ohio State University.
OUDIN, CHARLES P., 1323 3rd Ave., Spokane, Wash.	Mgr., American Fire Brick Co.
OVERBECK, ELIZABETH G., Cambridge City, Ind.	Student, New York State School of Clayworking and Ceramics.
PATTERSON, J. W., Anderson Ave., Wellsville, Ohio.	Mgr., Patterson & Son, Yellowware Potters.
PENCE, FORREST K., 1051 Linden Ave., Zanesville, O.	Ceramic Engineer, American Encaustic Tile Company.
PETERSON, RUDOLPH A., 108 Fulton St., New York City.	"Chemicals & Oils."
PFEIFFER, JACOB, 718 Bryden Road, Columbus, Ohio.	Pres., Logan Clay Products Co.
PHILLIPS, WILLIAM, 609 Haight Ave., Alameda, Cal.	Supt., N. Clark & Sons.
PITCAIRN, WILLIAM S., 44 Murray St., New York City.	Importer of China and Earthenware.
PITZER, N. G., Cherryvale, Kansas.	
PLUSCH, HERMAN A., B. Sc., Perth Amboy, N. J.	Chief Ceramic Chemist, Atlantic Terra Cotta Company.
PODMORE, JOSEPH, 309 2nd St., Troy, N. Y.	Asst. Supt., Ostrander Fire Brick Company.
POOLE, JOSHUA, East Liverpool, Ohio.	Mgr., Homer Laughlin China Company.
PORTER, ALFRED S., 573 E. 114th St., Cleveland, Ohio.	Sales Mgr., Kenilworth Tile Co.
POST, MALCOLM P., Commerce, Mo.	Post Bros. Drain Tile Works.
POWELL, WILLIAM H., 200 W. 70th St., New York City.	Pres., Atlantic Terra Cotta Co.
PRESTON, FRANCIS C., 509 Cuyahoga Bldg., Cleveland, O.	Vice Pres. and Sales Mgr., Dover Fire Brick Company.
PRICE, F. N., 315 Monmouth St., Trenton, N. J.	Gen. Mgr., Electric Porcelain & Manufacturing Company.
PURINGTON, D. V., 922 Chamber of Commerce, Chicago, Ill.	Chairman Board of Directors, Purington Paving Brick Company.
PYATT, FRANK E., Box 163, Milltown, N. J.	Supt., New Brunwick Tile Company
RAMSEY, ANDREW, Mt. Savage, Md.	Manufacturer of Enameled Brick.
RANDALL, JAMES E., Indianapolis, Ind.	Junior Editor, "Clayworker."

RANDALL, THEODORE A., Indianapolis, Ind.	Editor, "Clayworker."
RAYMOND, GEORGE M., 1511 Grand Ave., Dayton, Ohio.	Gen. Mgr., C. W. Raymond Co.
REA, WILLIAM J., Buffalo, N. Y.	Supt., Buffalo Pottery Company.
REYNOLDS, PIERCE B., Van Asselts Sta., Seattle, Wash.	Asst. Supt., Denny-Renton Clay & Coal Company.
RHEAD, FREDERICK HURTEN, University City, St. Louis, Mo.	Lewis Publishing Co.
RITTER, A. G. VAN BRIGGLE, Colorado Springs, Colo.	Pres. and Art Director, The Van Briggle Pottery Company.
RIVERS, WILLIAM EDWARD, Old Bridge, N. J.	Vice Pres., Old Bridge Enameled Brick Company.
ROBINEAU, S., St. Louis, Mo.	The Peoples University, University City.
ROBINSON, LOUIS G., 4th and Park Ave., Newport, Ky.	
RODGERS, EBEN, Alton, Ill.	Secy. and Treas., Alton Brick Co.
ROESSLER, FRANZ, 39 High St., Perth Amboy, N. J.	
ROGERS, GREGORY L., Grafton, W. Va.	Asst. Supt., Thornton Fire Brick Co.
ROWE, JOHN, Zanesville, Ohio.	Asst. Supt., American Encaustic Tiling Company.
RUTLEDGE, WILLIAM ASKINS, 33 East Green St., Champaign, Ill.	Student, University of Ilinois.
SANT, JOHN, East Liverpool, Ohio.	Clay Salesman, Miner and Broker.
SANT, THOMAS HERBERT, East Liverpool, Ohio.	Clay Salesman, Miner and Broker.
SAUEREISEN, FRED, Pittsburgh, Pa.	Supt., Porcelain Dept., Nernst Lamp Company.
SHAW, JOSEPH BRADFIELD, CR. E., Grand Rapids, Mich.	Enameler, Grand Rapids Refrigerator Company.
SIMPKINS, RALPH, St. Louis, Mo.	Mgr., Union Pressed Brick Co.
SINCLAIR, HERBERT, Trenton, N. J.	Gen. Mgr., Star Porcelain Co.
SINGER, L. P., Lincoln, Cal.	Chemist, Gladding, McBean & Co.
SMITH, ALBERT E., Trenton, N. J.	Foreman, Electric Porcelain Co.
SMITH, AMEDEE M., 515 Beck Bldg., Portland, Oregon.	Pres., Western Clay Mfg. Company.
SMITH, HARRY W., 314 Smith St., East Liverpool, O.	Representative, Roessler & Hasslacher Chemical Company.

SMITH, PERRY A., New Brighton, Pa. — Secy., A. F. Smith Company.

SOLON, ALBERT L., 228 N. San Joaquin St., Stockton, Cal.

SPEIR, HARRY F., Lewistown, Pa. — Supt., Pennsylvania Pulverizing Co.

SPIKER, JOHN A., Salt Lake City, Utah. — Gen. Mgr., Western Clay Products Company.

STALEY, HOMER FRANCIS, A. B., Columbus, Ohio. — Assistant Professor Department of Ceraimc Engineering, Ohio State University.

STAMM, JOHN, 859 Ohio Ave., East Liverpool, O. — Supt., National China Company.

STEVENSON, WILLIAM G., East Liverpool, Ohio. — Gen. Mgr., Ohio Silica Company.

STOLP, CHARLES, Chicago Heights, Ill. — Ceramic Engineer, Stolp & Weiderhold.

STOWE, CHARLES BROWN, Cleveland, Ohio. — Pres., National Fire Brick Company.

STUART, EARL KELLOGG, Champaign, Ill. — Student in Ceramics, University of Illinois.

STULL, RAY THOMAS, E. M. (in Cer.) Urbana, Ill. — Asst. Professor of Ceramics, University of Illinois.

TAKAHASHI, KAKUICHIRO, CR. E., Clarksburg, W. Va. — Chemist, Hazel Atlas Glass Co.

TAYLOR, WILLIAM WATTS, Cincinnati, Ohio. — Pres., Rookwood Pottery Co.

THOMAS, CHAUNCEY RAPELJE, Deerfield, Mass. — Deerfield Pottery.

THOMAS, DAVID C., Minerva, Ohio. — Ceramic Chemist and Head Burner, Owen China Company.

THOMAS, GEORGE W., East Liverpool, Ohio. — Pres. and Gen. Mgr., The R. Thomas & Sons Company.

THRALL, CHARLES U., Tottenville, S. I., N. Y. — Supt., Atlantic Terra Cotta Company.

TONE, FRANK J., Niagara Falls, N. Y. — Works Mgr., Carborundum Co.

TOPPING, J. A., 95 1st Ave., Columbus, Ohio. — With N. L. C. Kachelmacher.

TOWNSEND, EVERETT, 344 Bellevue Ave., Trenton, N. J. — Gen. Mgr., Robertson Art Tile Company.

TURNER, JAMES, 314 Cayuga St., Syracuse, N. Y. — Supt., Iroquois China Company.

VEIOCK, ALBERT, Monmouth, Ill. — Supt., Monmouth Mining & Mfg. Company.

VODREY, WILLIAM E., East Liverpool, Ohio. — Gen. Mgr., Vodrey Pottery Company.

VOLZ, WILLIAM J., St. Louis, Mo. — Supt., Evens & Howard Fire Brick Company.

WAGNER, FRITZ, 1000 Clybourn Ave., Chicago, Ill.	Vice Pres. and Treas., The Northwestern Terra Cotta Company.
WALCOTT, BENJ. D., Indianapolis, Ind.	Pres., Indianapolis Terra Cotta Company.
WANKA, LOUIS, Clayton, Wash.	Supt., Terra Cotta Department, Washington Brick, Lime & Mfg. Company.
WANKA, O. FRED, Clayton, Wash.	Supt., Washington Brick, Lime & Sewer Pipe Co.
WELLS, HARRY B., Greensburg, Pa.	Supt., Brick Company.
WEST, HARRY HYDE, 20 Plympton St., Woburn, Mass.	Chemist.
WHEAT, HOWARD I., 987 Sterling Place, Brooklyn, N. Y.	Asst. Supt., Chestnut Ridge White Brick Company.
WHITEHEAD, C. LOUIS, Box 153, Trenton, N. J.	Pres., Providential Tile Company.
WHITMER, J. D., CR. E., Willamina, Oregon.	Chemist with Pacific Face Brick Company.
WHITTAKER, JOHN L., Waltham, Mass.	Supt., O'Hara Waltham Dial Co.
WILL, OTTO W., Perth Amboy, N. J.	Supt., Color Dept., Roessler & Hasslacher Chemical Company.
WILLIAMS, ARTHUR EDWARD, 509 E. Healy Street, Champaign, Ill.	Student, University of Illinois.
WILLIAMS, IRA A., M. SC., Ames, Iowa.	Associate Professor, Geology and Mining Engineering, Iowa State College.
WILLIAMS, WARREN S., 908 South 5th Street, Champaign, Ill.	Research Assistant, Department of Ceramics, University of Illinois.
WIRT, HERBERT C., Burrage, Mass.	President, Wirt Mfg. Company.
WORCESTER, WOLSEY G., Columbus, Ohio.	Instructor in Ceramic Engineering, Ohio State University.
WORTH, S. HARRY, 706 Franklin Bank Bldg., Philadelphia, Pa.	Pres., Pennsylvania Feldspar Company.
YATES, ALFRED, Shawmut, Elk Co., Pa.	Gen. Mgr., Shawmut Paving Brick Company.
YOUNG, GEORGE F., Zanesville, Ohio.	Mgr., Roseville Pottery Company.
YOWELL, JOHN BENNETT, Urbana, Ill.	Student in Ceramics, University of Illinois.
ZOPFI, ALBERT S., Toledo, Ohio.	Secy. and Treas., Buckeye Clay Pot Company.

ANNUAL REPORT OF BOARD OF TRUSTEES.

Pittsburgh, Pa., February 7, 1910.

To the Members and Associates of the American Ceramic Society:

We take pleasure in submitting to you the Twelfth Annual Report of the Society, covering the period February 1, 1909 to February 1, 1910.

VOLUME XI.

Volume XI makes another handsome and creditable addition to the list of our publications. It contains 44 pages of matter relating to the business or administrative side of our work, 576 pages of text on 40 different subjects of interest in the Ceramic world, and 12 pages of index, the latter a new and very desirable feature. Such mechanical features of Volume X as were new to our publications were retained in Volume XI: viz., better paper, and cloth binding for a part of the issue. Our experience has shown that a large portion of the members are willing to pay the added cost of a good binding, but that some are not, and in deference to this situation, the policy of preparing the book in both forms will probably become a fixed one. Our bill-heads for dues, etc., will hereafter contain appropriate provision to cover the binding item for those who desire it.

In the matter of time of delivery there has been some improvement, but far less than was confidently expected by the Secretary and Editor. The work was begun promptly after the meeting this year and with the intention to break all records. The matter was substantially all ready for printing by the middle of April, and a contract was entered into with the lowest bidders, who also promised the quickest delivery. The printing company, however, failed most seriously to carry out their obligations, and consumed eighteen weeks instead of the twelve they were expected to use, judging by the amount of matter set. It seemed at times that they were indifferent as to meeting their obligation.

The efforts of the Secretary and Editor to get the volume out early were, therefore, largely frustrated by a cause beyond their control, and which is not likely to ever occur again. In spite of this unfortunate affair, the book appeared in the midde of August. The experience of this year indicates that it should be possible to get Volume XII out by July 1st, if no unusual delays occur.

The Editor profited largely by the experience gained in Volume X, and gave the Society's interests his whole time and attention for some months, and only took up other matters when the delay of the printing company left him with insufficient work to keep busy. Some unfortunate

errors in proof reading crept into the book, and have been set right as far as possible by an errata sheet sent out subsequently. But, in spite of these faults, the Board considers the book a creditable one, and thinks that the Editor has given excellent service.

THE FINANCIAL STATEMENT.

The statement following is a balance of the books of the Society for the year February 1, 1909, to February 1, 1910:

INCOME.

Brought forward from preceding year			$252.11
From Dues and Initiation Fees			
295 associates for 1909 at $4.00, plus foreign exchange	$1,180.18		
2 associates for 1909 at $3.50 (partly prepaid 1908)		7.00	
48 associates initiation fees at $5.00		240.00	
4 associates dues for 1910 at $4.00 (paid in advance)		16.00	
1 associate's dues for 1910 at $5.00 (paid in advance)		5.00	
51 members dues for 1909 at $5.00		255.00	
1 member's fees for 1909 at $3.00 (partly paid 1908)		3.00	
1 member's dues for 1910 at $5.00 (paid in advance)		5.00	
5 members initiation fees for 1909 at $5.00		25.00	
12 associates dues for 1908 at $4.00		48.00	
1 associate's dues for 1908 at $3.00		3.00	
4 members dues for 1908 at $5.00		20.00	1,807.18
Book binding fund			93.20
From Sale of Publications.			
Volume I	16		
Volume II	19		
Volume III	15		
Volume IV	15		
Volume V	13		
Volume VI	11		
Volume VII	14		
Volume VIII	15		
Volume IX	15		
Volume X	21		
Volume XI	41		$631.09

Manual 8		6.73
Branner Bibliography 19		40.21
Seger's Collected Writings, Volume I 6		45.00
Seger's Collected Writings, Volume II 6		45.00
Total Receipts		$2,920.52

DISBURSEMENTS.

Cost of Publishing Volume XI.		
Stenographic report, balance to Mrs. Kalb....	$297.55	
Stenographic report, Mr. W. R. Lansing.....	25.00	
Illustrations, drawings and engravings.....	128.31	
Printing, binding and casing Volume XI.....	974.10	
Editor's salary	600.00	$1,997.96
Cost of Collected Writings of Seger.....		63.72
Cost of running Secretary's Office.		
Salary of Assistant Secretary.....	300.00	
Postage, stationary and supplies.....	130.00	
Express on Transactions	70.63	
Convention circulars, notices, etc.....	28.26	
Telegram	0.32	
Insurance on Transactions	10.00	
Corporation fees, 1908 and 1909.....	2.00	
Cost of binding extra sets of Volumes I to IX to order	23.10	564.74
Outstanding Accounts.		
Bad account charged off.....	3.20	
For dues and fees	113.00	
For Transactions	70.44	
For Branner Bibliography	3.60	
For Seger's Collected Writings.....	30.00	220.24
Cash on Hand		12.20
Cash in Bank		61.66
Total		$2,920.52

This statement shows a fairly favorable situation. We have paid our bills, and have a balance on hand. We have increased our salaries by $100.00, and as explained before, have paid at least $100.00 too much for our printing, but otherwise the year's work is not dissimilar from the past.

On the other hand, there are some disquieting features: We have sold about $450.00 less of our literature, we have made no substantial headway in disposing of the Branner Bibliography, and we have a slight increase in the amount of outstanding accounts.

The decline in the sale of our literature, while not conducive to our growth, is still not an unnatural or unexpected event. The market for our material is of course limited, and we have already begun to feel this. Efforts have been made as usual to sell full sets to all newly elected members, and also we have continued to allow book sellers a 20 per cent discount, in the hope of increasing their sales. The most notable fall in the sales list is in Seger's Collected Writings, which are becoming increasingly difficult to dispose of, year by year.

The outlook for the ensuing year is, nevertheless, good. We may expect that the receipts from dues and fees will increase probably more than enough to offset any shrinkage in sales that is likely to occur. There are no increased expenses to face, and there is one notable economy in sight, viz., the cost of the stenographic report. The elimination of from $125.00 to $150.00 of travelling expenses from this item will more than cover the increased cost of using two separate reporters for our double session plan. There seems no reason, therefore, why a gross income of $3,000.00 cannot be relied upon for next year. With this amount, the work of the Society can go forward comfortably on the present basis, but cannot expand into any new fields.

PUBLICATIONS.

The annual inventory of the publications is as follows:

	Remain'g on hand Feb. 1st, 1909	Received Since	Disposed of since by sale or otherwise	In stock according to books	In stock by actual inventory
Volume I	223	...	16	207	207
Volume II	211	...	19	192	192
Volume III	217	...	15	202	202
Volume IV	187	...	15	172	172
Volume V	155	...	13	142	142
Volume VI	184	...	11	173	173
Volume VII	187	...	14	173	174
Volume VIII	179	...	15	164	164
Volume IX	152	...	15	137	137
Volume X	208	...	41**	167	167
Volume XI	0	600	395†	205	205
Manual	9	...	9*	0	0
Branner Bib.	859	...	19	840	839
	2771	600	597	2774	2774

* 1 defective copy discarded. 8 sold.

† 321 issued to members, 31 given to libraries and journals, and contributors who were not members. 43 sold.

** 1 copy free to replace 1 lost in mails.

The change in the status of the publications is not marked. We have sold our last copy of the "Manual," and in consequence, there have been a few extra sales of Volume II, which contains this useful little booklet as an appendix.

There are eight of the eleven volumes on which the price has been increased owing to the number of remaining copies falling below 200. The other three volumes will be marked up for the same reason in the very near future. A revision of the price to be charged for the volumes when they fall below 100 copies is perhaps needed, in the interest of keeping up our revenue.

The books are still stored in the School of Mines Building of the Ohio State University, in a room devoted to that purpose only, and are insured in the sum of $2,000.00. The total value represented by them, at the rate of $3.00 per volume of the Transactions and $0.50 per copy of the Branner Bibliography, is $6,224.50.

GROWTH IN MEMBERSHIP.

The year has been a good one. Our rolls stand as follows:

Brought forward February 1st, 1909.		
Honorary members	2	2
Full members, resident	47	
Full members, foreign	3	50
Associates, resident	225	
Associates, foreign	26	251
Total		303
Accession During Year.		
By election to full membership, resident	5	
By election to full membership, foreign	0	5
By election to associate membership, resident	50	
By election to associate membership, foreign	5	55
Total		60
Losses During Year.		
By death (Stanbery, Carmichael, Zimmerman)	3	3
By resignation, members	1	
By resignation, associates	8	9
By failure to pay dues and fees	7	7
By promotion to full membership	5	5
Total		24

Present Status.

Honorary members	2	2
Full members, resident	51	
Full members, foreign	3	54
Associate members, resident	251	
Associate members, foreign	33	284
Total		340

This statement shows that the Society is most vigorously alive and growing, and that the exceptional growth of 1908 has been duplicated in 1909. The percentage of full members is 15.8 to 83.6 associates. It would be desirable to increase the list of full members so as to make it a larger proportion of the whole, but the Board feels strongly that it would be a mistake to do so, by in any way lowering the standards which have been maintained in the matter for years past. It really devolves upon the associates to win their promotion. They have the knowledge that the Board is anxious to promote all who will show themselves able and willing to meet the unwritten requirements.

THE CLAY PRODUCTS LABORATORY.

The work done by the Society in assisting in the foundation of the Clay Products Laboratory of the Technologic Branch of the United States Geological Survey is well known. This year witnessed our still further activity in striving to keep what we had won and to broaden its scope. Our influence in the form of political pressure on members of Congress was undoubtedly felt, not only in securing the appropriation necessary to continuation of the work, but also in seeing that the Clay Products division was fairly treated in the distribution of the appropriation after it was in the hands of the Technologic Branch.

The present legislation before Congress, looking to the establishment of a Bureau of Mines under the Secretary of the Interior, and the transfer to this Bureau of all of the activities now carried on by the Technologic Branch of the Geological Survey, is of much importance to us. The appointment of a committee to deal with this matter and to direct the work of the Society into useful channels in behalf of this plan was made by President Purdy during the year, to begin work as soon as the legislation in Congress was formally introduced, and this committee has been active in its work. The advantages sought in this transfer to a permanent Bureau of Mines is to secure permanence or continuity of work and opportunity to plan consecutive studies covering a term of years which is impossible on the present hand to mouth system, with a sense of insecurity overhanging the corps of investigators all the time. It is hoped that this year will see this important step carried through finally, and the

permanence of Ceramic investigation established as a part of the Government's work. We consider that the work planned and carried out so far by Director Bleininger and his corps reflects great credit on their industry, enthusiasm, and intelligence, and justifies all our efforts to support this Bureau.

SUMMER MEETING.

The summer meeting at Kittanning, Ford City and Pittsburg proved a most satisfactory and delightful occasion. The opportunities extended to us to visit interesting plants were in excess of our time to accept them, and every minute was filled with an active, pleasant program. The choice of Pittsburgh for this winter's meeting by the National Brick Manufacturers' Association was made without opportunity for conference on the part of our Society, and would not have been our choice on account of the summer's session having been at this point, but the advantages of meeting at this same city seemed too great to justify separating on this ground alone.

The policy of appointing the committee for the summer meeting six months in advance, at the winter meeting, has proved its value on the first trial, and will doubtless be made a regular part of our program hereafter.

CONTRIBUTING MEMBERSHIP.

The plan discussed and formulated two years ago has not yet been put into operation. The employment of a paid Editor for the last two years and the action of the Society one year ago in the matter of an Assistant Secretary has reduced the acuteness of the need of more funds than we can secure in the regular way. There has been some criticism of the legality and propriety of the use of the title Assistant Secretary for a person who is not a member of the Society. It is probable that the title Accountant would be better suited to describe the duties of the present incumbent. The increase in wages and in responsibility has certainly worked very advantageously during the past year. The question of the title is of less importance, and is open to adjustment at the Society's pleasure.

The Secretary has recommended that no change in the mode of raising funds be tried this year, in order that a strictly normal year's income and expenditure may be compared, and in this the Board concurs.

REVISING THE RULES.

The work of the Society has proceeded steadily for twelve years past, with scarcely any modification of the original rules. As may be imagined under these circumstances, the practices of the Society in many

ways have grown *beyond* the rules, although in some matters it is perilously close to being contrary to them. There is a considerable body of precedent, which we have been calling the "unwritten law," etc., which might better be incorporated into the rules and thus made regular. The Board recommends the appointment of a committee of five to revise the rules, and that their report shall be published with the nominations for officers in December, 1910, and shall be submitted to letter ballot in January, 1911, and that the passage of this resolution shall constitute the year's notice of desire to amend, now required by the rule on amendments.

Respectfully submitted,

THE BOARD OF TRUSTEES,
By Edward Orton, Jr.,
Secretary.

TREASURER'S REPORT FOR THE YEAR ENDING FEBRUARY 1, 1910.

DEBITS.

To balance from last report	$252.11	
To February collections	348.52	
To March collections	552.75	
To April collections	273.50	
To May collections	218.31	
To June collections	205.51	
To July collections	135.31	
To August collections	128.68	
To September collections	145.95	
To October collections	97.17	
To November collections	188.21	
To December and January collections	141.56	$2,687.58

CREDITS.

By vouchers attached	$2,625.92	
By bank balance per book attached	61.66	$2,687.58
Vouchers attached completing last year's report	550.00	

Respectfully submitted,

ELLIS LOVEJOY,
Treasurer.

We, the undersigned, have examined the above report and the vouchers and bank book submitted, and find the same correct in all respects.

W. T. T. BOWMAN,
STANLEY BURT,
JOS. B. SHAW,
Auditing Committee.

RULES.

OBJECTS.

The objects of the American Ceramic Society are to promote the arts and sciences connected with Ceramics by means of meetings for social intercourse, for the reading and discussion of professional papers, and for the publication of professional literature.

MEMBERSHIP.

The Society shall consist of Honorary Members, Members and Associates.

Honorary Members shall be persons of acknowledged professional eminence, and shall not exceed five in number.

Members shall be persons competent to fill responsible positions in Ceramics and have suitable qualifications.

Associates shall include persons interested in Ceramics and the allied arts.

Honorary Members shall be proposed by at least five members, approved by the Board of Trustees, and receive at least 90 per cent of the votes cast by letter ballot at the annual meeting.

Members and Associates shall be proposed by at least three Members or Associates, approved by the Board of Trustees, and receive at least 75 per cent of the votes cast by letter ballot. A candidate for admission must make application on a form prepared by the Board of Trustees which shall contain a written statement of his age, professional experience, and that he will, if elected, conform to the laws, rules, and requirements of the Society.

All Honorary Members, Members and Associates shall be equally entitled to the privileges of membership, except that only Members shall be entitled to hold office and to vote. Applicants for a change in grade of membership shall conform to the requirements of a new applicant.

Any person can be stricken from the membership of the Society on the request of five or more members, on the recommendation of a majority of the Board of Trustees, if he fails to resign on the advice of the Board of Trustees. Such person, however, shall be first notified of the charges against him, and be given a reasonable time to appear before the Board of Trustees, or present written defense, before final action is taken by the Board of Trustees.

DUES.

Honorary Members shall be exempt from all dues.

The initiation fee of Members shall be ten dollars, and of Associates five dollars, which if not paid within six months after election, will render the election void.

The annual dues for Members shall be fixed by the Board of Trustees, but shall not exceed five dollars per year.

The annual dues for Associates will be fixed by the Board of Trustees, but shall not exceed four dollars per year.

Any Member or Associate in arrears for over one year may be suspended from membership by the Board of Trustees until such arrears are paid.

OFFICERS.

The affairs of the Society shall be managed by the Board of Trustees, consisting of a President, Vice President, Secretary, Treasurer, and three Trustees, who shall be elected from the members at the annual meeting, and hold office until the adjournment of the meeting at which their successors are elected.

The President, Vice President, Secretary and Treasurer shall be elected for one year, and the Trustees for three years; and no President, Vice President, or Trustee shall be eligible for immediate re-election to the same office.

The duties of all officers shall be such as usually appertain to their offices, or may be delegated to them by the Board of Trustees or the Society; and the Board of Trustees may at its discretion require bonds to be furnished by the Treasurer.

Vacancies in any office shall be filled by appointment by the Board of Trustees, but the new incumbent shall not thereby be rendered ineligible to re-election at the next annual meeting to the same office. On the failure of any officer to execute his duties within a reasonable time, the Board of Trustees, after duly warning such officer, may declare the office vacant, and appoint a new incumbent.

A majority of the Board of Trustees shall constitute a quorum; but the Board of Trustees shall be permitted to carry on such business as it may desire by letter.

ELECTIONS.

At the annual meeting, a nominating committee of five Members, not officers of the Society, shall be appointed, and this committee shall send the names of the nominees to the Secretary at least 60 days before the annual meeting, who shall immediately forward the same to the Members. Any other five members may also present the names of any candidates to the

Secretary, provided it is done at least 30 days before the annual meeting. The names of all candidates, provided their assent has been obtained, shall be placed on the ballot without distinction as to nomination by the regular or an independent nominating committee, which shall be mailed to every member, not in arrears, at least 20 days before the annual meeting. The ballot shall be enclosed in an inner blank envelope, and the outer envelope shall be endorsed by the voter, and mailed to the Secretary for collection. The blank envelopes shall be opened by three Scrutineers appointed by the Chair at the annual meeting, who will report the results of the election. A plurality of the votes cast shall elect.

MEETINGS.

The annual meetings shall take place on the first Monday in February, at such place as the Board of Trustees may decide, at which time reports shall be made by the Board of Trustees, Treasurer, and Scrutineers of election, and the accounts of the Treasurer audited by a committee of three apopinted by the Chair.

Other meetings may be held at such times and places during the year as the Board of Trustees may decide, but at least 20 days' notice shall be given of such meetings.

Seven members shall constitute a quorum at any regular meeting, and a majority shall rule except when otherwise specified.

The order of business at the annual meeting shall be:

1. Reading of Minutes of last meeting.
2. Reports of the Board of Trustees and Treasurer of the Society.
3. Announcement of Election of Members.
4. Announcement of Election of Officers.
5. Appointment of Nominating Committee.
6. Old Business.
7. New Business.
8. Reading of Papers.

PUBLICATIONS.

The Board of Trustees shall act as a Publication Committee, and decide as to what to publish. The publications of the Society shall be sent to all Members and Associates not in arrears. The Secretary will furnish each author with reprints of his papers at cost price, provided due notice is given that reprints are desired.

The Society is not, as a body, responsible for the statements or opinions expressed in its publications.

PARLIAMENTARY STANDARD.

Roberts' "Rules of Order" shall be the parliamentary standard on all points not covered by these rules.

AMENDMENTS.

These rules may be amended at any regular meeting by a two-thirds vote of a letter ballot at the subsequent annual meeting, provided a written notice of such proposed change is sent to each member at least 30 days before said annual meeting. Said proposed amendments shall be printed on the ballot for officers and counted by the same Scrutineers.

PUBLICATIONS.

DESCRIPTION OF VOLUME.		Price to Members.	Price to Others.
Vol. I.	Transactions for 1899, 110 pages,		
	Bound in paper,	$1.00	$4.00
	Bound in cloth,	1.75	4.75
Vol. II.	Transactions for 1900, 278 pages,		
	Bound in paper,	3.00	4.00
	Bound in cloth,	3.75	4.75
Vol. III.	Transactions for 1901, 238 pages,		
	Bound in paper,	3.00	4.00
	Bound in cloth,	3.75	4.75
Vol. IV.	Transactions for 1902, 300 pages,		
	Bound in paper,	3.00	4.00
	Bound in cloth,	3.75	4.75
Vol. V.	Transactions for 1903, 420 pages,		
	Bound in paper,	3.50	5.00
	Bound in cloth,	4.25	5.75
Vol. VI.	Transactions for 1904, 278 pages,		
	Bound in paper,	2.50	4.00
	Bound in cloth,	3.25	4.75
Vol. VII.	Transactions for 1905, 454 pages,		
	Bound in paper,	3.25	4.50
	Bound in cloth,	4.00	5.25
Vol. VIII.	Transactions for 1906, 411 pages,		
	Bound in paper,	3.00	4.00
	Bound in cloth,	3.75	4.75
Vol. IX.	Transactions for 1907, 808 pages,		
	Bound in paper,	4.00	5.50
	Bound in cloth,	4.75	6.25
Vol. X.	Transactions for 1908, 582 pages,		
	Bound in paper,	3.75	5.00
	Bound in cloth,	4.25	5.50
Vol. XI.	Transactions for 1909, 632 pages,		
	Bound in paper,	4.50	6.00
	Bound in cloth,	5.00	6.50
Vol. XII.	Transactions for 1910, (*in prep.*)		
	Bound in paper,	4.00	5.50
	Bound in cloth,	4.50	6.00
Cost of complete set,			
	Bound in paper,	38.50	55.50
	Bound in cloth,	46.75	63.75

DESCRIPTION OF VOLUME.	Price to Members.	Price to Others.
The Collected Writings of Dr. Hermann August Seger, Volume I. Contains (A) Treatises of a general scientific nature. (B) Essays relating to Brick and Terra Cotta, Earthenware and Stoneware, and Refractory Wares. Pages 552. Bound in cloth,	7.50	7.50
The Collected Writings of Dr. Hermann August Seger, Volume II. (B) Essays on White Ware and Porcelain. (C) Travels, Letters and Polemics. (D) Uncompleted works, and extracts from the archives of the Royal Porcelain Factory. Pages 605. Bound in cloth,	7.50	7.50
A Bibliography of Clays and the Ceramic Arts, by Dr. John C. Branner, 1906, 451 pages. Bound in cloth. Contains 6027 titles of works on Ceramic subjects,	2.00	2.00

At the Cincinnati meeting, the Board of Trustees fixed a sliding scale of prices to apply to the sale of volumes of the Transactions, when the number unsold falls below 200 copies. As the copies become scarcer, prices will be increased to both members and others. The supply of all of the volumes has already fallen below 200 copies, and some of the volumes will probably fall below the 100 mark this year. Members and Associates who do not yet own full sets are advised to procure them at once.

At the same meeting the following resolution was adopted:

Resolved, that the custom by which members and associates may obtain copies of the Transactions at reduced or so-called "members' rates," is intended only to enable each person to obtain one complete file of the transactions.

The necessity for this resolution arose from the expressed desire of a member to buy a copy of the transactions, with the intent to sell it to a friend for whom he wished to save the additional price charged to non-members. In accordance with the spirit of this resolution the Secretary will not supply more than one copy of a volume to a member at reduced rate, except when loss or destruction of a volume gives good cause for so doing.

Every member or associate receives one copy of the Transactions free for each year for which he pays dues. He is entitled to purchase copies for the years antedating his connection with the Society at the costs indicated in the first column. All others can obtain copies at the prices listed in the second column by sending order, accompanied with check, to

EDWARD ORTON, JR., *Secretary.*

Columbus, Ohio.

OBITUARY NOTICES.

C. IRVING ZIMMERMAN.

Mr. C. Irving Zimmerman met an untimely death as the result of an accident while canoeing on Lake Mendota, at Madison, Wisconsin, May 29, 1909. He was born in Milwaukee, February 6, 1881. He spent five years in the University of Wisconsin, taking his Bachelor of Science and Electrical Engineering degrees. Here his work was exceptional, and he took a great deal of extra work. He was elected to membership in the honorary engineering fraternity of Tau Beta Pi. His thesis on the Aluminum Electrolytic Condenser was the basis for several papers and further work in that line later which attracted a great deal of attention here and abroad. He was graduated in 1903. His first work outside of the University was as an apprentice with the Westinghouse Electric & Manufacturing Company, Pittsburgh, where he spent nearly two years. From here he was transferred to the Nernst Lamp Company, where he made several important discoveries and improvements, particularly in glower construction, and in the chemistry of the glower. He was next employed by the Carborundum Company, of Niagara Falls, as metallurgical engineer, where he made decided advances in electric furnace work and silicon furnaces. He remained here three years when he decided to go back to the University of Wisconsin, to carry on some original work where he could have at his disposal laboratory facilities for the analyses of raw materials. In addition, he took up wireless telegraphy and perfected some new detectors that are being used with great success.

He had a fine analytical mind, was able to balance theory and practice in a remarkable way. He was an enthusiastic instructor, and his enthusiasm was infectious, his students and colleagues having for him the greatest admiration and affection.

He was a member of the American Electrochemical Society; The American Institute of Electrical Engineers; The American Chemical Society; The American Ceramic Society; The American Association for the Advancement of Science; and the British Society of Chemical Industry; and recently he was elected a member of the honorary fraternity of Sigma Xi. Among the more important papers contributed by him to technical literature were the "Aluminum Electrolytic Condenser," "Some Physical Properties of Silicon," "Concentric Tubular Conductors for Electric Furnace Feeders." He was a fine fellow with a clean moral sense, and was an ardent worker for high scientific development. His place will be hard to fill.

GEORGE A. STANBERY.

George A. Stanbery, general superintendent of the American Encaustic Tiling Company, died March 23, 1909.

He was born in 1847 in Zanesville, Ohio. Growing up as a youth in that city, he was apprenticed at the age of 16 to the machinist's trade. His training was interrupted for a time by the civil war, in which he participated as early as his youth would permit enlistment. Returning from the war, he followed his trade as a journeyman machinist in the Brooks Locomotive Works, at Dunkirk, N. Y. Here his mechanical ability was recognized, and he was sent to Vienna by the government in 1870 in connection with the Exposition held there, and subsequently was given a place in the U. S. Arsenal at Philadelphia. He left this work to become the mechanical expert for a knitting machine company in Norfolk, Va., where he made a number of valuable inventions.

His connection with the ceramic industries began about 1877 when, returning to his native town, and finding the clay industries beginning to assume importance, he interested himself in a roofing tile proposition. This speedily led him into the exacter problem of making flooring tiles. Here his fine mechanical training and experience with both ponderous and delicate machinery and his undoubted inventive genius immediately made itself felt. He invented a machine for manufacturing tiles by the dry press process, which has been wonderfully successful. He recognized at once the principles of successful expulsion of air from a dry-press powder, and by his toothed cam gave the kneading pressure, which solved at once the problem of sound dry-pressed wares. Subsequently, his skill was applied to one step after another of the process of clay preparation, manufacture, sizing tiles, dipping and glazing, etc.

His master work was the planning and execution of the great plant of the American Encaustic Tile Works Company, the largest in the world of its kind, and a model of factory design for economy of production and efficiency. Over this great works he presided for 16 years, as the ruling spirit of both officers and men.

Stanbery was a man of genial, kindly temper, generous to business competitors, and helpful in suggestions to those who came to him for advice. His achievements in ceramics were naturally along the mechanical side of the subject, as his early training gave him no opportunity to acquire an insight into the chemical side. But his contributions to the industry are nevertheless great and enduring, and in connection with his lovable personality made him easily among the first men of the American tiling industry of his day.

EDWARD ORTON, JR.

PAPERS AND DISCUSSIONS.

ON THE DETERMINATION OF HYDRATED SILICIC ACID IN CLAY.

BY

FORREST K. PENCE, Zanesville, Ohio.

The presence of hydrated silicic acid in clays is said to have a marked influence upon their drying and vitrification behavior.

Wm. H. Zimmer[1] explains the abnormal shrinkage and early vitrification of certain kaolins by the presence of hydrated silicic acid. He determines this silicic acid by treating the clay with caustic soda. But practically any clay will yield a notable quantity of silica when treated with this powerful reagent.

E. Orton, Jr., in unpublished lectures, quoting mainly from Zimmer, points out that the presence of this colloid produces increased drying shrinkage with a corresponding tendency toward cracking; also that hydrated silicic acid in a clay provides silica in an extremely finely divided form during vitrification. This silica is, therefore, more easily attacked by fluxes and promotes vitrification to a greater extent than does an equal amount of finely ground quartz. Colloidal silica also gives increased translucency.

Because of the importance of the presence of colloidal silica in clay, a practical method for its quantitative determination is sought in this investigation.

In the Analyst for 1903, page 123, is given an abstract of an article by B. Sjollema, in which he says:

"Quartz can not be quantitatively separated from amorphous silica either by means of sodium hydroxide or by sodium carbonate solution. The former dissolves a little quartz as well as non-crystalline silica, and with the

[1] Trans. Amer. Cer. Soc., Vol. III, p. 25-45.

latter it is difficult to bring all the amorphous silica into solution. It follows, therefore, that the work of Von Piedzicki, who determined the proportion of free silica in soils by boiling the samples for an hour and a half with 10% NaOH, is valueless.

The separation, however, may be effected by the use of solution of methylamine, or preferably diethylamine. A 33% solution of diethylamine dissolves 0.6 gram of amorphous silica to within 0.0002 gram if it is boiled therewith for about 8 hours, and a 16.5% solution of methylamine acts similarly."

In the above article, the terms referring to the silica determined are used rather loosely, but it is inferred from the context that by amorphous silica is meant the same as is usually called colloidal silica, or hydrated silicic acid.

The organic solvents mentioned in the above article are too expensive for use in practical commercial analysis.

An article entitled "The Qualitative Detection of Colloidal Silicic Acid," by Hugo Herman, appears in Zeitschrift für Analytische Chemie, Vol. 46, pp. 318-320. An abstract of the same appears in Chemical Abstracts, Vol. 2, No. 2, p. 244.

The method described involves the boiling of the sample in a solution of sodium paratungstate, when colloidal silica is taken into solution as sodium silicotungstate ($5Na_2O.SiO_2.12WO_3$). The caesium salts of both the above acids are quite insoluble. Caesium paratungstate, however, is soluble in an acetic acid solution of sodium acetate, while caesium silicotungstate is insoluble in such a solution. A method of separation is thus afforded. To the original solution containing sodium silicotungstate and the excess of sodium paratungstate is added a quantity of a solution of acetic acid and sodium acetate in water (15 grams crystalline sodium acetate 25cc water, 5 grams of 98% acetic acid). Upon the addition of caesium chloride solution, caesium silicotungstate alone is precipitated. The article states that further work will be done to deter-

mine the possibilities of the method for the quantitative determination of colloidal silica.

The reagents mentioned in the article are quite expensive and hence impractical for ordinary analytical work.

In Mead's "Examination of Portland Cement," p. 119, the following method is given:

Boil four or five grams of clay directly with strong sodium carbonate solution in a platinum dish. Filter and wash with hot water and determine SiO_2 in filtrate in the usual manner.

In an article in the Transactions of the American Ceramic Society, 1901, pp. 25-45, Dr. Zimmer describes a method in which he treated the clay with caustic soda and determined the silica dissolved. He corrected for the SiO_2 taken from the clay by deducting from the first result, the SiO_2 corresponding to the alumina also taken into solution.

In Comptes Rendus, Oct. 19, 1908, pp. 660-662, Le-Chatelier states that it is probable that the properties of gelatinous silica are due to the extremely fine state of division, and that definite hydrates of silica probably do not exist. He supports this hypothesis by arguments regarding chiefly the physical properties of gelatinous silica.

Whether or not definite hydrates of silica exist does not appear as yet to have been proven by physical-chemical methods. It is understood, however, that by the term "hydrated silicic acid" is meant the colloidal forms of silica which contain various amounts of water. The physical form is well known even though its chemical structure has not been conclusively demonstrated.

It was decided to investigate the use of sodium carbonate in determining colloidal silica, and also whether a slight amount of sodium hydroxide in addition is necessary or permissible.

To this end, a clay was prepared which should be free from hydrated silicic acid, and to a sample of five grams

of this clay, a known quantity of SiO_2 as the colloidal hydrate was added. The recovery of the SiO_2 was then attempted by various methods.

Preparation of Hydrated Silicic Acid. A quantity of a solution was prepared as follows: One part of commercial sodium silicate (water glass) to five parts of water was acidified with one part of strong hydrochloric acid to five parts of water. The resulting solution was practically as fluid as water, and no gelatinous silica was precipitated at this dilution.

This solution was then placed in tubes of parchment paper, known as dialysis tubing. The tubes were then suspended in a glass cylinder containing pure water, and the solution allowed to dialyze. The water in the cylinder was poured off at intervals and pure water added until by dialysis, the solution within the tubes was free from chlorides and contained only gelatinous silica, which was now in the form of a rather stiff jell. A portion of this jell was tested for purity with hydrofluoric acid, and gave no residue. About two weeks were required for the dialysis treatment.

The gelatinous silica was diluted in a beaker with about three times its volume of water, and placed on a steam hot plate and allowed to digest until a fairly homogeneous solution was obtained. This was filtered through common filter paper by suction in order to exclude any hardened particles that had not gone into solution.

In this way a homogeneous, slightly opalescent solution was obtained. It had practically the same fluidity as water. Twenty-five cubic centimeters of this solution were found to contain 0.1765 gram of SiO_2.

At the close of this investigation, the solution was examined under a polarizing microscope by C. H. Kerr, and showed no evidence of crystallization or non-homogeneity. A portion evaporated to dryness at 45° centigrade also showed no evidence of crystallization. A portion of the solution evaporated to dryness at 100°C and main-

tained at this temperature for some hours still contained 7.2% of water.

The solution described above afforded a convenient means for the addition of a known amount of SiO_2 as hydrated silicic acid, to a clay sample.

Preparation of the Clay. The clay used was a crude kaolin from the Harris mines at Dillsboro, N. C., which contained considerable free quartz and mica. This was ground to a fine powder, and the samples used were treated as follows:

A sample of 5 grams of kaolin was boiled 30 minutes with 300 cubic centimeters of a 20% sodium hydroxide solution. The kaolin was allowed to settle and the supernatant liquid poured off. The kaolin was then washed with hot water until washings were neutral to litmus paper. The sample was then dried on the steam plate, and to it were added 25cc of the standard SiO_2 solution. This was evaporated to dryness at or near 45° C.

In this way the dried colloidal silica was deposited as a surface film upon the grains of clay in much the same way as it would probably be deposited in nature. The treatment of the clay with the 20% NaOH solution would remove any hydrated silicic acid originally in the clay. We have then, finally, a sample of clay containing 0.1765 gram of SiO_2 as hydrated silicic acid, and the problem is to find a quantitative method for recovering it.

Quantitative Determinations. (1) To a sample prepared as described above, 200 cc of 5% sodium carbonate solution were added, and the whole digested in a porcelain casserole on a water bath for twenty minutes. The solution was filtered through hardened filter paper into a porcelain casserole and the clay washed with hot 5% Na_2CO_3 solution. The SiO_2 in the filtrate was determined in the usual way, by acidifying with hydrochloric acid and evaporating to dryness. Two evaporations were made, and the SiO_2 obtained was corrected by use of hydrofluoric acid.

In this and subsequent determinations, all digestions, boilings and evaporations were carried on in six-inch porcelain casseroles. Baker's sodium carbonate was used. No trouble from clay passing the filter paper was experienced when hardened filter papers were used.

SiO_2 recovered .....0.1310 gram
SiO_2 unrecovered .....0.0455 gram

(2) Method same as in (1) except that the sample was digested with 10% sodium carbonate solution.

SiO_2 recovered .....0.1456 gram
SiO_2 unrecovered .....0.0309 gram

(3) To the sample in a casserole, 120 cc of 5% sodium carbonate solution were added. A watch glass was placed over the casserole and the solution boiled for ten minutes over a free bunsen flame, the casserole being given a slight rotary motion to prevent bumping. The watch glass and sides of the casserole were then rinsed down with hot water and the clay allowed a short time to settle. The solution was then decanted through a hardened filter paper. A second treatment was then given, repeating the process above described. The treatment was then repeated for the third time, and the clay transferred to the filter paper and washed with hot dilute sodium carbonate. The SiO_2 in the combined filtrates was then determined by the usual method.

SiO_2 recovered .....0.1767 gram
SiO_2 excess .....0.0002 gram

(4) Method same as in (3) except that a solution containing 5% sodium carbonate and 1% sodium hydroxide was used in the boiling treatments.

SiO_2 recovered .....0.2287 gram
SiO_2 excess .....0.0522 gram
SiO_2 excess = 1.04% of a 5 grams sample.

(5) The sample consisted of the prepared clay alone. No silicic acid was added to it. In this way the SiO_2

obtained from the clay, ware, and reagents is determined. The method used was that described in (3), using 5% Na_2CO_3 solution.

SiO_2 obtained .....0.0148 gram
SiO_2 obtained = 0.30% of a 5 grams sample.

(6) Sample used was identical with that used in (5). The method was the same as that in (4).

SiO_2 obtained .....0.0711 gram
SiO_2 obtained = 1.42% of a 5 grams sample.

(7) No sample of clay nor silicic acid was used. Method was that given in (5). The determination is a blank on the ware and the reagents.

SiO_2 obtained .....0.0084 gram
SiO_2 obtained = 0.17% of a 5 grams sample.

(8) Five grams of flint fire clay were treated in the same way as was the kaolin prepared for the above samples. To the clay thus prepared, 25 cc of the SiO_2 solution were added and evaporated to dryness at or near 45° C. SiO_2 was recovered by method described in (3).

SiO_2 recovered .....0.1828 gram
SiO_2 excess .....0.0063 gram
SiO_2 excess = 0.13% of a 5 grams sample.

The residue remaining from the treatment of the ignited SiO_2 with hydrofluoric acid was so small as to be negligible in all determinations.

Conclusions. It is seen from determinations (4) and (6) that even a small amount of sodium hydroxide used with sodium carbonate in the method described causes considerable error. A notable amount of SiO_2 that is not present in colloidal form is brought into solution.

The use of sodium carbonate as described in (3) gives fairly accurate results as shown in (3) and (8). When colloidal silica is present in amounts of 1% to 3%, or greater, the errors tend to balance each other.

In case a determination shows such SiO_2 to be present

in amounts of 4% or greater, a smaller sample should be used and the determination repeated.

The method is not sufficiently delicate to detect 0.1% to 0.2% of SiO_2 in colloidal form in a clay, since this amount could easily be obtained from the ware and clay alone. Platinum vessels should be used, if possible, especially in determining small amounts of colloidal SiO_2.

The method described in (3) should be sufficiently accurate for practical determinations, in which is sought an explanation of the peculiar physical properties of certain clays.

An extended research would be necessary to determine the possible errors involved in the method, the extent to which minerals common to clays are attacked by sodium carbonate solution. The use of a clay containing free quartz, mica, etc., was taken to demonstrate this to the extent possible in a limited investigation.

The method should be tried on extremely fine powders of quartz, mica, feldspar, etc., to determine to what extent silica will be taken into solution from these minerals when they are present in very finely divided form. If in these determinations, the solution of silica does not give rise to serious error, the accuracy of the method for practical purposes would seem to be established.

The method described in determination (3) was used in the following:

I—Flint Fire Clay. This clay was selected for the following reasons:

It has peculiar physical properties, as conchoidal fracture and lack of plasticity.

In chemical composition it almost corresponds to pure kaolinite.

It often occurs in juxtaposition with fire clays of good plasticity and high silica content. The origin of flint fire clay remains as yet inexplicable.

Sample .....5.0000 grams
SiO_2 obtained 0.28%

The result gives no more SiO_2 than would probably be obtained from attack of the clay and the ware as shown by the previous blank determinations. We conclude that this sample of flint fire clay is practically free from hydrated silicic acid.

II—A Stratified Kaolin. This kaolin, from Trinity, Walker County, Texas, gave erratic results in the determination of colloids as devised by H. Ashley. It vitrifies at about cone 2 to a hard translucent body. The kaolin contains about 5% of alkalies (K_2O plus Na_2O).

Sample .....5.0000 grams
SiO_2 obtained 2.20%

III—A Red-Burning Clay. This clay, from Fort Pierre, N. D., is very plastic, having a peculiar stickiness. It is practically impossible to dry the clay without its cracking. The cracking was greatly reduced by heating the clay dry at 250° C for one hour before tempering and molding. This did not entirely overcome the cracking, which took place even with slow and careful drying. When fired at cones 1 to 3, the clay gives a total shrinkage of 22%.

Sample .....5.0000 grams
SiO_2 obtained 4.48%

As this was more SiO_2 in colloidal form than had been recovered in establishing the process of analysis, the determination was made on a smaller sample.

Sample .....2.5000 grams
SiO_2 obtained 5.56%

This latter figure is probably a little high, due to the greater relative error produced by SiO_2 as obtained in the blank on the ware, etc.

It is shown that the sample contains a notable quantity of colloidal silica, a fact which offers explanation of its physical properties.

The major purpose of this investigation is the determi-

nation of hydrated silicic acid in clays. As a matter of interest, an experiment was made which would indicate the effect of hydrated silicic acid in a white ware body.

Bodies were prepared from the following materials:

Clay Mixture
- English China Clay No. 7.....25
- Harris Dillsboro China.....25
- Georgia Washed Kaolin.....25
- English Ball No. 12.....25

Golding's Flint.
Golding's Spar.

Bodies were made as follows:

Body I
- Clay Mixture 50
- Flint 40
- Spar 10

Body II
- Clay Mixture 50
- Flint 25
- Spar 25

To the prepared bodies were added amounts of SiO_2, as indicated in table of results, as gelatinous silica prepared pure by dialysis.

The tests were tempered to as nearly the same consistency as was possible, and molded into test bars 2.5 centimeters $\times$ 2.5 centimeters $\times$ 11 centimeters long. All test bars dried easily and without cracking. They were fired together to cone 8.

Absorptions were determined by boiling in water for one hour, followed by soaking for twenty-four hours.

	SiO_2 added as Hydrate	Absorption	Shrinkage Drying	Shrinkage Firing
Body I	0.0	3.10	Not det.	Not det.
	0.5	4.35	4.50	7.90
	1.0	5.03	6.00	7.50
	2.0	7.70	6.25	7.25
Body II	0.0	0.11	4.5	9.25
	1.0	0.05	6.0	9.00
	2.0	0.18	7.0	9.50

All the above results are given in per cents.

Results from Body I are consistent and more reliable than those from Body II, since vitrification in the latter has progressed so far that slight differences are accidental.

The results show decreased vitrification with increased colloidal silica, acting much the same as would a similar increase in flint.

The increased drying shrinkage is such as would be expected.

The evidence concerning the effect of hydrated silicic acid upon vitrification is contrary to conclusions drawn by Dr. Zimmer. The method of preparing and adding the hydrated silicic acid to the prepared body as described in this experiment should give more reliable results than could be obtained by Dr. Zimmer's methods, especially the one which supported his conclusion that hydrated silicic acid produces a lowering of the temperature at which vitrification occurs.

I wish to acknowledge my obligation to Prof. Edward Orton, Jr., for helpful suggestions received during the course of this investigation.

THE MANUFACTURE OF CRUCIBLES, SCORIFIERS AND MUFFLES.

BY

A. F. GREAVES-WALKER, Salt Lake City, Utah.

In this paper the writer hopes to set forth a brief outline of one of the most interesting branches of the Ceramic industry.

There are but six plants in the United States manufacturing assay goods from clay, and three manufacturing crucibles and muffles from a mixture of graphite and clay.

The manufacture of this kind of ware is in itself a very simple proposition, but it carries with it problems that can only be solved by a very close study of conditions under which the ware is used.

For instance, in making a crucible or scorifier mix, a thorough knowledge of the action of almost every known combination of fluxes, metals and metallic oxides on a silicate of alumina is necessary. Copper ores (usually sulphides) when in the fluid state are very active when in contact with a body high in alumina, yet very much less active in contact with a high silica body. On the other hand, lead ores will hardly intrude in a crucible body high in Al_2O_3, but will eat through a high silica body in a very short time. Nearly all ores contain either one or the other of these metals or a combination of the two. So in the first place a body must be made which will successfully stand off intrusion of both of these metals and any other metal or combination of metals or fluxes that may come in contact with it.

The above are some of the chemical considerations. The physical considerations also present difficult problems. A crucible body must be of such porosity as to permit its being plunged from the temperature of the air into

a white-hot muffle having a temperature of 2000° F., and at the same time of such density as to prevent such thin fluid fluxes as borax glass and potash or fluid lead from intruding in the slightest degree. This latter problem is one of the hardest presented, as the crucibles are sometimes exposed to high heats for long periods. After being exposed to the high heat on the outside and the fluid flux and metal on the inside, the thin walled crucible must retain its shape and rigidity so that it can be picked up with the tongs and withdrawn from the muffle or furnace without crushing or disintegrating.

The many different methods used by assayers and the vast difference in the composition of ores and fluxes must also receive consideration. In parts of Nevada muffles are not used, the crucible being held by a support and the flame of a gasoline blast lamp thrown on one side. This, of course, causes an intense heat on the side exposed to the blast while the other side remains comparatively cool. A harder condition than this can hardly be found, and very few crucibles will stand this sort of treatment. Add to this the fact that some assayers expect to use a crucible for at least six charges and an even harder condition has to be met.

Some assayers use only a coke fire, burying the crucibles in the red coals of a pot furnace. With the softening influence of the charge inside and the presence of the fuel outside, there is a great tendency on the part of the crucible to squeeze flat, resulting in the loss of the charge.

In the Cripple Creek District of Colorado and the Butte District of Montana, the deep mines are producing only heavy sulphides. To reduce these sulphides iron nails are placed in the crucibles. The chemical action resulting from the reduction is so severe on the crucible that even the best will sometimes go down under this test. The fluxes, especially where the nails touch the crucible walls, simply eat their way through.

It is impossible to make a special crucible for each particular use, the low price of this class of ware prohibit-

ing it. It is therefore essential that a natural body be found that will successfully answer all purposes in the great majority of cases. Such natural bodies have so far proved scarce.

CLAYS.

The clays successfully used are all No. 2 fire clays. They differ from the Eastern No. 2 fire clays in that they are harder and have a laminated shaly structure, caused by the crumpling of the Rocky Mountains. In Colorado, the clay used in Denver and Pueblo is mined near Golden and analyzes as follows:

SiO_2	71.81	46.88
Al_2O_3	15.09	35.42
Fe_2O_3	1.75	1.74
CaO	.14	.44
MgO	.05	.20
Alk.	1.02	1.19
H_2O	10.14	14.10
	Cone of fusion 30	Cone of fusion 33-34

In Utah, the clay used is mined about forty miles due south of Salt Lake City in the Oquirrh Range, and analyzes as follows:

	Utah Fire Clay Company	Western Clay Products Company
SiO_2	44.08	58.99
Al_2O_3	31.84	30.71
Fe_2O_3	3.20	.57
CaO	.45	.70
MgO	.92	.40
Alkalies	3.20	.94
TiO_2	1.38	.32
H_2O	15.17	7.30
	Cone of fusion 30	Cone of fusion 34

All of these clays are much the same in appearance, although the Colorado clays are much the hardest and require a good deal of tempering and soaking before they can be used. Clays for this purpose are all hand picked, care being taken to reject all clay that is iron stained or containing iron particles or nodules in any form, as the bubbles resulting would cause weak spots in the walls of the ware.

The same clays are used in making crucibles, scorifiers and muffles, but in each case the amount of grog or calcine used, the fineness and the treatment is different.

The Battersea, (England), works also uses a No. 2 fire clay for crucibles, but a highly micaceous kaolin for scorifiers. One crucible mix analyzes as follows:

SiO_2	72.39%	
Al_2O_3	25.32%	
Fe_2O_3	1.07%	
CaO	.38%	Calcined
MgO	Trace	
K_2O	1.14%	
Na_2O	Trace	
Total	100.30%	

Some manufacturers use flint or porphyry for grog instead of calcined clay. In this case the grog is added in the raw state.

PREPARATION OF CLAYS.

The preparation, of course, depends upon the character of the clay used. With the hard varieties the method is as follows:

After being hand sorted, either at the mines or in the yard, it is placed in small piles and allowed to weather for a variable length of time, depending usually upon the amount on hand. It is ground to 20 mesh for crucibles and 40 mesh for scorifiers in a dry pan or mill, mixed with the proper amount of grog, (which is ground and screened separately), in a long mixer of the pug mill type. The amount of grog used in the crucible and scorifier mixes varies from 30% to 40%. When the clay and grog have been thoroughly mixed into a stiff mud, lumps of it are laid around on pallets in a warm room. When dry these lumps are broken up and the same process repeated. When again dry the lumps are broken up and pulverized and the material run into bins.

When needed at the machines, small quantities are run into shallow bins, spread out and slightly wetted with a sprinkling can. When evenly tempered it is rubbed

through a coarse screen to break up all lumps, and is then ready for use.

When softer clays are used, such as are found in Utah, less work is required in preparing them for use.

The clay is carefully picked over at the mine and sacked, no weathering being necessary. The clay and grog are then mixed together in lump form in the same proportions as mentioned above for the harder clays. This mix is fed into a pan or mill and run over screens, (either 20 or 40 mesh according to its use), direct to the storage bins. From these bins it is run into shallow bins and wetted down with a sprinkling can. In about 12 hours it is thoroughly tempered, and after rubbing through a coarse screen it is ready for the machine.

At Battersea the usual old English methods are followed. The clay is weathered in piles for long periods, ground, mixed with ground calcined clay and soaked in pits. As the English make part of their crucibles from stiff mud, the clay for these is used directly from the pits. The semi-dry crucibles made on the machines have their body prepared in practically the same way as described above for hard American clays.

Both in the United States and in England special crucibles are made for "open hearth" work. An "open hearth" crucible is buried in a hot coke fire instead of being placed in a muffle.

The one difference generally made in the mix for this class of crucibles is the removal of the fines from the grog. This is usually done by passing it over a 30 or a 40 mesh screen after having been first put through a 20 mesh. The resulting mix makes a crucible that will stand the severe work much better than with the fines left in.

The mix for scorifiers is practically the same as for crucibles, and is treated in the same manner. The proportions of clay and grog are in most cases practically the same, the one difference being the greater fineness of the grog.

Practically the only difference between the preparation of the mixes for crucibles and scorifiers and those for muffles is that the muffle mixes are very high in grog, from 60% to 75% being used, and it is very much coarser, generally over a 20 mesh and through a 4 mesh. Instead of pugging twice, the mix is given a single long treatment of two hours or more in a closed end pug mill. The mix is then put into bins and allowed to temper until needed for use.

METHOD OF MANUFACTURE.

Crucibles—(**Fig. 1**). Several different methods are used in making crucibles, (a) by hand on a wooden core,

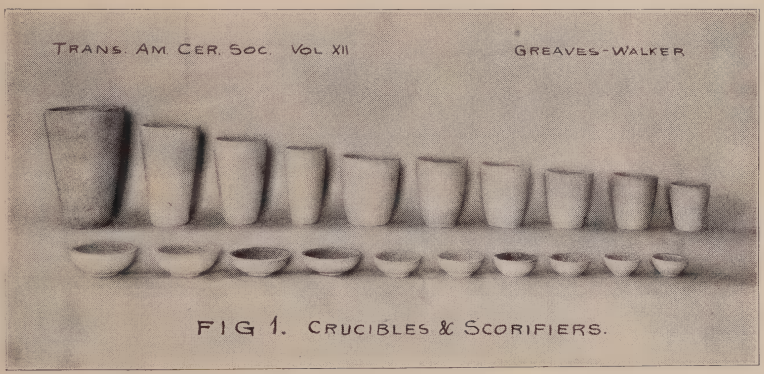
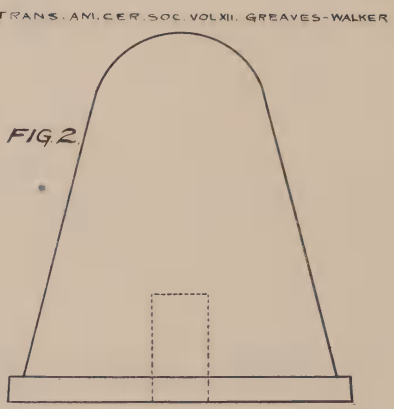


FIG 1. CRUCIBLES & SCORIFIERS.

(b) by hand in a plaster mould on a wheel, (c) on a hand power press, (d) on a power press.

Method a—This is the original English method, and is still used there in making "open hearth" shapes. It is as follows: A wooden core having the same shape as the inside of the crucible, and with a shoulder at the widest part by which to gauge the thickness (Fig. 2) is set on an iron spindle by means of a hole in the bottom. The spindle is set into a socket in the bench before which the moulder sits. The core may thus be revolved by hand. On the upper end or point of the core a lump of tempered clay is

placed. This is pounded and slapped until it covers the core down to the shoulder. A sliding vertical gauge fixed near the socket hole of the spindle regulates the outside shape and thickness of the crucible. When finished and smoothed the core is lifted from the spindle and inverted, the crucible easily slipping off. Sometimes on straight shapes a linen cover is put over the core in order that the crucible may slip away more easily. The pouring spout is made with the fingers.



Method b—Plaster moulds are used in the manufacture of black lead or graphite crucibles. A lump of the crucible mix is placed in the bottom of the mould, which is then put upon a power wheel. A template is used to form the inside. When smoothed up, the mould and crucible are removed to a dryer.

Method c—Two types of hand presses are in use. One is the ordinary Raymond Hand Repress, the mould and plunger for brick being replaced by a mould and plunger for crucibles. It is always necessary for the plunger, which forms the inside of the crucible, to revolve as the pressure is applied, otherwise the crucible will stick to it so hard that it is necessary to break it up in removing it.

Two methods were devised to accomplish this. One is to attach a bevel gear rigged to a pulley and belt which

keeps the plunger revolving continuously; the other is simply inserting a long iron bar in the plunger head (which hangs in a collar), and turning it as the mould is brought up and the pressure applied.

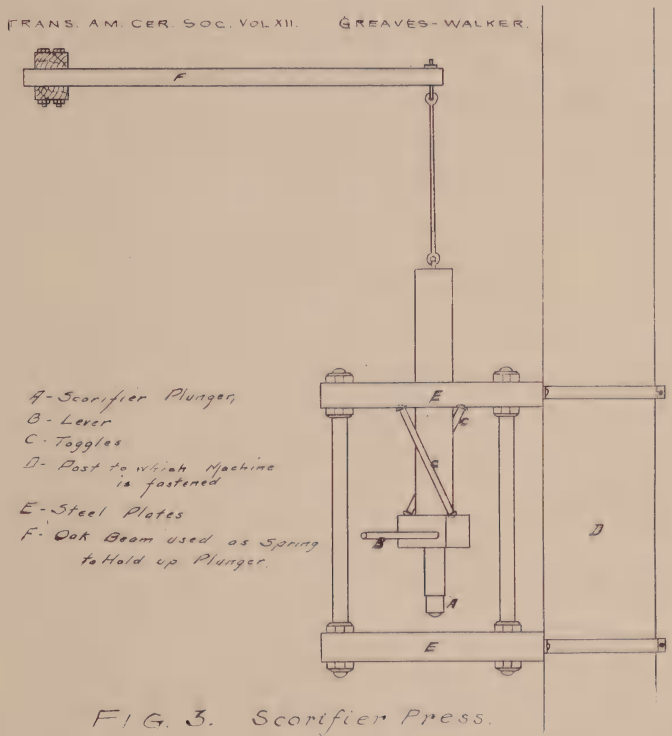


FIG. 3. Scorifier Press.

The other machine is slightly more complicated (Fig. 3). It works opposite to the Raymond press, the mould being stationary while the plunger is brought down into it and at the same time revolved. A bar inserted in the plunger head, with one motion, applies the pressure by bringing down the plunger, and at the same time gives the necessary rotary motion.

This is accomplished by means of two toggles, having balls at both ends which fit into sockets in the cross head

that holds the plunger and in a stationary plate above it. These toggles are set crosswise in the form of a letter X, one each side of the shaft to which the plunger is attached, and which extends up through the stationary plate mentioned above. This shaft is attached at the top to a strong spring which holds it up. With this arrangement a slight pull at the bar straightens the toggles to a vertical position, thereby giving the plunger a downward thrust that will exert tremendous pressure, and at the same time gives the necessary rotary motion to the plunger.

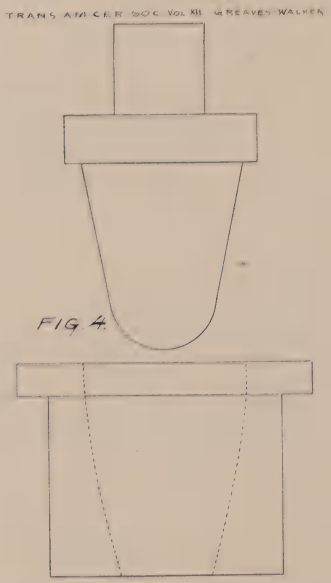


FIG 4.

On these machines a man can make 1000 to 1500 crucibles a day if his mix is in good working condition.

The moulds used on these machines are of soft steel, the inside being machined to the desired shape of the outside of the crucible, Fig. 4. The mould is open at the bottom, the steel plate on which it rests serving as such. After the crucible is pressed, the mould is slid from under the plunger on to a "kickout." This is a small steel disc at-

tached to a foot treadle and operates through a hole in the steel plate. A "trimmer" is then placed on the mould, and with a slight pressure of the foot on the "kickout" the crucible is pushed out of the mould, finished.

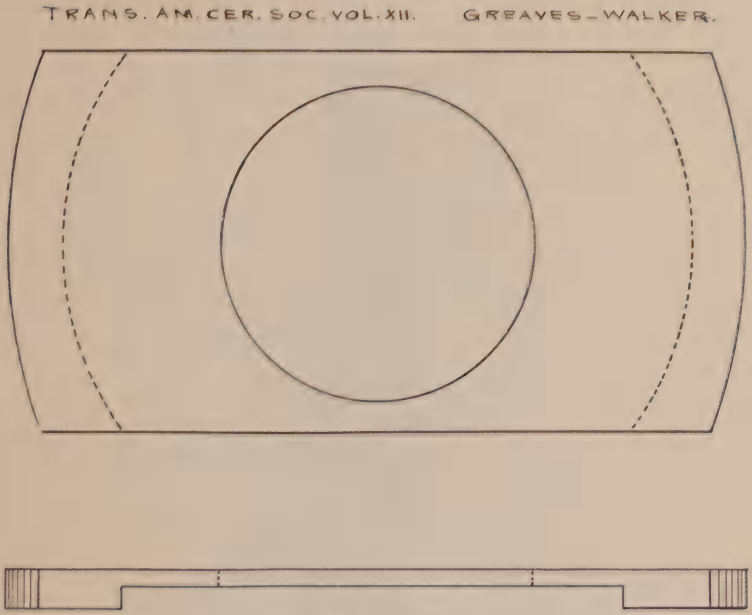


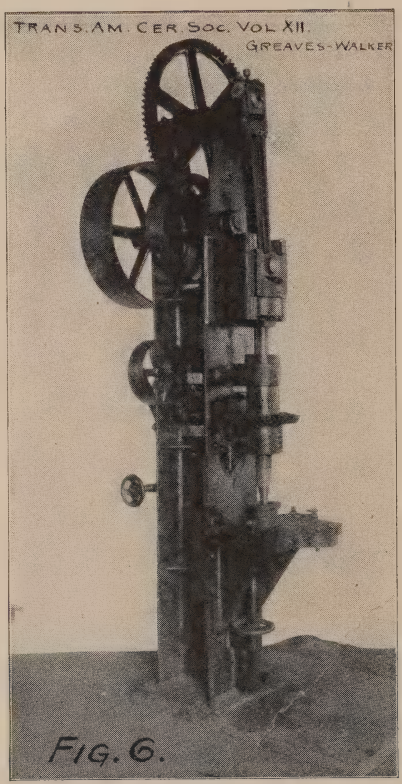
FIG. 5.

The "trimmer," Fig. 5, is simply a flat piece of steel having a hole in the center the exact size of the top of the crucible. When laid on the mould and the crucible kicked through it, it trims off the rough edges caused by the issue.

All moulds are slightly grooved vertically in several places on the inside. This is to prevent, to some extent, the crucible from twisting under the influence of the revolving plunger.

Twisting invariably means a flaw. It is caused by one portion of the crucible remaining stationary in the mould while another portion moves just the smallest fraction of

an inch with the plunger. The break is often covered up so neatly on the surface that it is not detected until the charge begins to run through on to the muffle bottom. This makes the twist the constant dread of the crucible manufacturer.



Method d—The power press is rather a simpler affair than is expected, Fig. 6. The pulley drives a set of gears that revolve the plunger constantly and at the same time give it an up and down stroke. Two men work at the press, each having a set of moulds, etc., and catching alternate strokes. The capacity of the machine is from 4000 to 5000 20-gram crucibles in 10 hours. The machine requires

from 2½ to 3½ horse power. The crucibles are kicked out of the moulds and trimmed in the same manner as described above for the hand power press.

Scorifiers—Fig. 1. Scorifiers are made on either the hand or power press in exactly the same manner as described for crucibles.

The capacities of the machines are practically the same when working on scorifiers as on crucibles. However, there is a greater loss on scorifiers on account of their tendency to blister under the pressure of the plunger. This is caused by their thickness and the almost flat inside surface.

Muffles. The making of muffles is an entirely different proposition from the processes described above. It is entirely a hand process at the present time. A wooden core is made having the shape of the inside of the muffle. This core has a shoulder at the front end by which the thickness is gauged and which gives the shape of the outside.

The core is thoroughly soaked in water before using, and is then completely covered with a sheet of thin wet canvas. This canvas prevents sticking and allows the core to be easily withdrawn from the completed muffle.

The clay is laid on a table which is covered with a loose sheet of canvas, and batted out with a wooden mallet into a sheet of the proper size and thickness, as shown by two gauge sticks tacked to the table. The canvas covered core is then laid on the clay, bottom down. The sheet of clay is then wrapped around it by means of the loose canvas sheet. It is joined along the top from end to end, the back brought up, trimmed and joined to sides and top, and the whole smoothed up with a trowel. The muffle is then set aside to dry slightly. In a few hours the core is removed and the muffle allowed to dry thoroughly, resting on its end.

As the muffle mixes are so high in grog there is not shrinkage enough to effect the pulling of the core, even though the body gets fairly hard and dry.

Drying: After being kicked out of the moulds, crucibles or scorifiers are set, bottom up, on slat pallets and placed on racks in a steam heated room. On account of their openness there is very little danger of loss during this stage.

Muffles are generally dried in an open warm room, no special care being necessary to prevent cracking.

FIG. 7.

Burning: In the case of the Colorado ware, the burning is all done in the same kilns as the fire brick, the crucibles, scorifiers and muffles being set on top of the brick benches. This means a temperature of from Cone 9 to 12.

In Utah, on account of the difference in the clay, the

ware is burned by itself in small square kilns to temperatures of from Cone 1 to 3.

The hardness or density to which the ware is burned depends on the nature of the clay used and the use to which it is to be put. For mill work, where a crucible must stand at least six charges and where no account is taken of a slight absorption of the ore values, the crucible must be soft to stand the several exposures to rapid changes of temperature. For custom smelter and custom assay office work, where a crucible is used but once and where no loss of values by absorption can be allowed, the ware can be harder, but in all cases it must be able to withstand the great temperature changes to which it is always subjected.

Scorifiers are generally burned softer than crucibles, as on account of their comparative thickness they are more likely to crack.

Crucibles are nested and burned bottom side up. (Fig. 7). Scorifiers, on account of the inability to nest, are burned in saggers or pockets made of brick. Muffles are simply scattered about on top of other ware and burned singly.

BLACK LEAD OR GRAPHITE CRUCIBLES.

The mixture used in the manufacture of these crucibles is about as follows:

Graphite	50%
Plastic Clay	45%
Sand or Grog	5%

The materials are crushed to pass a 40 mesh sieve and are mixed and tempered in a pug mill. After taking from the mill the mixture is tempered in a damp room for several days and is then ready for use.

The crucibles are made in a plaster mould on a wheel, the inside being shaped by a template or former.

The drying process is the same as for other ware made in plaster moulds.

The burning is done in saggers in which are placed pieces of coke. Reducing conditions are maintained as nearly as possible in order to prevent the loss of graphite. A week is generally required to burn a kiln.

These crucibles are not used in assaying, but for melting pots. The smaller sizes are mostly used in the manufacture of dental supplies, the larger ones in the metallurgical industries.

THE BRIQUETTING OF FUELS.

BY

CHARLES L. WRIGHT, Pittsburg, Pa.

GENERAL STATEMENT.

The term "briquetted fuel" is used in this country to designate a fuel made by compressing small pieces of coal in molds, with or without the addition of a binding material, so as to form pieces of even size of any desired weight or form which will not sift through the grates. In England this fuel is called patent fuel or artificial fuel, while in Belgium, France, and Germany it is known under various general terms such as "boulets," "agglomeras," etc. In Europe it is frequently the practice for makers to give trade names to the briquets manufactured by them, and in some cases this name is stamped on the face of the briquets by the press. This practice is being adopted in this country to some extent.

It may not be amiss to state here that before the briquetting industry will be entirely successful in this country, it will require chemical examination of the raw fuel and proper chemical control of the material at the different stages of the process. Also, the plant must be properly designated by competent engineers. I mention this because many inventors of new binders have the idea that they can make successful briquets without any experience with briquetting, and this ignorance has resulted in the wasting of considerable capital in this country.

The process of briquetting does appear simple enough on the surface. All one apparently has to do is to mix a binder (if required) with a fuel and press into blocks. It will be easily understood that, while the process is simple enough, there may be difficulties in mixing materials, heating them to just the right temperature, while keeping the

moisture content right, and in finding the proper press. However, there is nothing impossible in these days if there is money enough to make the proper investigation to find the right methods of procedure.

Briquetting schemes have failed in certain instances because they were not under proper technical supervision, or the supply of raw fuel or binder was uncertain, or poor judgment was shown in the location of plant to supply markets already supplied with good fuel at low prices.

Most of the briquetting plants in European countries are located at the mines and are owned by the mine operators, so that they may utilize the waste from the mines, in the case of the hard fuels, or can make low grade fuels such as lignites into briquets without transportation charges having been paid on the raw material.

I believe that success in the fuel-briquetting industry in this country will only be attained when our mine operators become sufficiently interested in this method of utilizing their mine waste, or in the case of lignites making a good fuel from inferior raw material, to install complete briquetting plants at their mines. With proper equipment and superintendence, plants so located should be a good investment for the operators.

There are several reasons for briquetting fuel, the most important of which are the following:

1. To convert mine waste into a commercial fuel.
2. To utilize the low grade fuels, such as lignite and sub-bituminous coals, peat, etc., and convert them into fuels suitable for local use where they are found.
3. To produce a satisfactory household fuel from bituminous coal, or refuse from coal yards.

1. In the modern methods of mining bituminous and anthracite coals, large quantities of slack and culm are produced, and while in some sections of the country there

is a market for the slack, for use in industrial plants provided with mechanical stokers, yet in other sections of the country there is not only no market for the slack, but the mine owners are put to a positive expense to haul it away from the mines and dump it in great piles, which frequently become fired by spontaneous combustion, being gradually consumed. For this reason the coal mine operators are at the present time interested in the development of the briquetting industry in this country, and even if the process should not yield much profit of itself, it would do away with the handling of the slack and convert it into a fuel that will readily sell for at least as much per ton, and usually for more than the best lump coal from the same mine. This saving and utilization of a by-product is strongly to be commended as helping to conserve our natural resources, a question which is arousing so much interest and thought at the present time.

2. To utilize the low grade of fuels of the West and South. In certain portions of the United States, notably Texas, North Dakota, Colorado, Montana, and California, are found beds of lignite covering large areas and from a few inches to over thirty feet in thickness. These lignite beds are in many instances situated long distances from bituminous and anthracite fields, and the obtaining of a satisfactory fuel supply is a problem of great interest to people living in these districts, as upon the solution of this problem depends the development of manufacturing industries there. Considerable interest has been manifested in the United States recently in the development of these fuel supplies of relatively low heating values. European countries have been developing and improving their low grade fuel supplies for many years, so that at the present time the artificial preparation of such low grade fuels as peat, lignite and sub-bituminous and the slack of bituminous and anthracite has become an extensive industry. Briquetting and the manufacture of producer gas have been the means most generally adopted in Europe to convert

these low grade fuels into useful fields, and the industrial success of Germany has been due in no small measure to the production of useful fuel from practically worthless raw material.

Lignites in their raw states are not satisfactory fuels for either domestic or industrial purposes on account of their inability to resist the effects of weathering. They crumble to slack when dried, and after exposure to wet and dry weather for a few weeks they become slacked to such an extent that they are burned with difficulty and only with special apparatus.

The American lignites tested by the U. S. Geological Survey were found to contain from 30 to 40 per cent of moisture at the mine, and this high per cent of moisture partially accounts for the low heat value and efficiency of this fuel. In the process of briquetting lignites the moisture is reduced to 10 to 15 per cent, and their heat values are thereby improved from 35 to 50 per cent. This improvement in heat value is of especial importance when the fuel is to be shipped to a market at some distance from the mine, as it saves transportation charges on the water that is removed by briquetting, this saving amounting to as much as 32% in some instances.

3. To produce a satisfactory household fuel from bituminous coal. In certain parts of this country, notably New England, where fuel has to be obtained from mines located at a distance, the transportation charges are so great that the prices of anthracite and bituminous coals are sufficiently close to each other so that when the added advantage of the cleanliness of the hard coal is considered it is not strange that anthracite is used for a domestic fuel to the exclusion of bituminous coal.

In these sections there should be a market for bituminous coal briquets as a house heating fuel, as they could be made at the mines and sold at a price to compete with anthracite, and if properly made (and I must emphasize the word properly), the briquets should have satisfactory

heating capacity and cleanliness to compare with hard coal.

BRIQUETTING WITH BINDER.

Most fuel materials can be briquetted if the proper binder is used and the proper briquetting conditions are determined. Naturally some material will cost more to briquet than others, and whether a certain fuel can be briquetted on a commercial scale with profit will depend on several conditions such as

Cost of raw material.
Cost of binder.
Amount of binder required.
Action of material in press.
Amount of moisture in raw material.

Binders Used.

The largest item of the cost of briquetting, using a binder, is the cost of the binder itself, and so it is not surprising that in the last fifteen years thousands of patents have been issued in different countries for binding materials for briquetting fuels. Many of them are complex, being made up of several substances, but the greater number of them have not been found practical, as in some cases the cost was prohibitive, while in other cases the complex nature of the binder made the briquetting process too complicated.

Among the materials suggested for binders, the following may be mentioned: Clay, lime, magnesia, plaster of Paris, Portland cement, natural cement, water glass, rosin, pitch, pine wood tar, hardwood tar, wood pulp, sulphite liquor (from paper mills), sulphite pitch (from sulphite liquor), beet pulp, lime cake, beet sugar molasses, cane sugar molasses, corn starch, potato starch, flour, flax straw, flax straw syrup, slaughter house refuse, garbage, blast furnace tar, producer gas tar, illuminating-gas tar, by-product coke-oven tar, coal-tar creosote, water gas tar,

pitches of various grades made by distilling these tars, natural asphalts such as impsonite, gilsonite, maltha, refined Trinidad, etc., crude petroleum, petroleum residuum, wax tailings, acid sludge, asphalt tar, Pintsch-gas tar, etc.

Of these binders, only a few have been found practical and those in actual use at the present time are fewer yet. Coal tar pitch is the binder most generally used in Great Britain, Germany, France, and Belgium. The U. S. Geological Survey has found water-gas-tar pitch an excellent binder, and it is the binder most generally used on the tests made by the Survey.

Sulphite liquor and cell pitch, by-products of the wood pulp paper industry, although at first not found satisfactory binders on account of not making waterproof briquets, have lately been used with more success, and in the Pollacsek process in Hungary cell pitch has a favorable outlook.

In this brief paper I will not try to discuss the binders in detail, and those interested will find this subject treated in an admirable manner by James E. Mills in the U. S. Geological Survey Bulletin No. 343, entitled "Binders for Coal Briquets." It would be wise, however, to describe here the following binders:

(a) Coal tar pitch is obtained from the distillation of coal-tar, a by-product of the coal-gas industry. There are three grades of this pitch, namely, soft, medium, and hard pitch. Soft pitch has greater binding power than the hard pitch and therefore less of it is required, but it has the disadvantage of producing more smoke and softening at a lower temperature in the fire. All tar pitches have the disadvantage of producing smoke when burned, but as they make waterproof briquets they have been extensively used in European countries for making coal briquets.

(b) Water-gas pitch is made by distilling water-gas tar, which is a by-product of the water-gas industry. This pitch is therefore a petroleum product, as it comes from the petroleum oil used to enrich the water gas. What was

said above about the characteristics and grading of coal-tar pitch applies equally well to water-gas pitch.

(c) Asphalt pitch is derived from natural bituminous rock such as impsonite, gilsonite, maltha, etc., and is probably superior in binding qualities to coal, tar and water-gas pitch, but has as yet been used only to a limited extent.

BRIQUETTING WITHOUT BINDER.

Certain kinds of lignites, or brown coals, possess sufficient binding qualities to be briquetted without adding any artificial binder to them, although a much higher pressure must be used than when briquetting material with added binder, as this pressure is necessary to soften the inherent binder.

Lignites suitable for briquetting without binder are found in Germany, Austria, Italy, and the United States.

Germany is the greatest producer of lignite briquets, having made 14,227,218 tons of this fuel in 1908, while Austria comes next with 130,000 tons in the same year.

A special type of press, known as the Exter-press, is used in Germany for briquetting lignite and peat, but the latter fuel is not briquetted profitably at the present time on account of the high moisture content which must be removed by drying. Peat has been more successfully prepared for fuel by air drying and wet pressing in presses similar in construction to those used for making clay products.

DRYING OF FUEL BEFORE BRIQUETTING.

Some fuels, but more especially lignites and peat, require drying before briquetting.

Lignites fresh from the mines in Germany contain as high as 60% of moisture, and samples of American lignites investigated by the U. S. Geological Survey have contained as high as 42% of moisture. Before briquetting this fuel it must be dried considerably so as to contain from 5 to 15 per cent of moisture in the briquets.

If dried too much it will not briquet. Therefore, to make briquets successfully from lignites requires close control of the drying, and the amount of moisture is the most important factor in briquetting this fuel.

Drying lignites improves their heat value as much as 50%, and drying is necessary not only to improve the heat value but, more important still, the drying is required to prevent too much steam being formed in the dies while pressing, as when sufficient steam is formed the pressure blows the briquet material out of the mold with great violence. Again, with certain lignites the presence of too much water causes "water cracks" in the finished briquets, which are the result of the steam formed acting as a cushion in the mold and when the pressure is relieved the steam expands, cracking the briquet.

In Germany there are two general types of driers in use in briquetting plants.

One of them, the plate type, consists of a series of circular steam heated plates arranged one above the other, over which plates the material is moved by scrapers from the center toward the outer edges of one plate, then drops through holes onto the plate below, is scraped from the outer rim toward the center of this plate, then drops through holes onto the next lower plate, and so on through the drier.

On account of the large number of moving parts in the plate drier and their liability to get out of order, this type of drier is gradually being superseded by another type of drier, known as the Schulz drier. This Schulz drier resembles a multitubular boiler supported on bearings at each end, in an inclined position, so that by revolving the drum the material will move through the tubes by gravity. These driers are 21 to 26 feet long and 7 to 11½ feet in diameter, and have 240 to 364 drying tubes 3¾ inches in diameter, so they have 4640 to 8180 square feet of heating surface and will dry in 24 hours from 45 to over 70 tons of wet lignite.

Other types of driers are more commonly used in this country for drying materials such as the long hollow cylindrical driers placed in an inclined position, and heated by direct heat while revolving, the gas passing through the cylinder in some cases.

For drying and heating bituminous or anthracite coal for briquetting, another type of drier known as the Bietrix furnace, is used in France. It consists of a circular brick chamber in which is revolved a circular horizontal table. Direct heat is passed over this table from a fire box at the side. Scrapers move the coal, while drying, from the center to the outer edge of the table, where it is discharged through openings in the casing. This type of drier is said to be continuous and highly efficient in action.

PRESSES.

The presses used for briquetting fuel are of three general classes:

Class (I) Open mold machines.
Class (II) Closed mold machines.
Class (III) Tangential or rotary machines.

The space allotted to this paper allows of only a brief discussion of the various types of presses.

Class I. Presses of the open mold class are, as the name suggests, provided with molds open at one end, and the pressure is obtained by the resistance offered to the material in passing through a gradually narrowing opening. Presses of this class are in use in brick and tile industries, and the auger brick machine may be mentioned as typical. For fuel briquetting, open mold machines are used commercially only for briquetting lignites and peats, although a press with open molds has been used to some extent in Belgium for briquetting washed coals containing as high as 20% of water.

The following fuel briquet presses belong to this type:

1. The Exter press.
2. Bourriez press.

3. A press known in England as Johnson's briquet press, but which must not be confused with the Johnson press belonging to the Survey, which is of an entirely different type.

4. Max Everard's briquet press.

5. A peat briquetting machine known as the Schlickeysen peat machine, which is typical of other peat machines.

Class II. Briquet presses having closed mold may be divided into two types:

(a) Single compression machines.

(b) Double compression machines.

(a) In the single compression machine the material in the mold is compressed by a plunger from one side of the mold only, while in the double compression machines both sides of the briquet are simultaneously compressed by double plungers, and the resultant briquets are more homogeneous than those made by the single compression machines.

As types of the single compression machines the following may be mentioned: Thomas Middleton's press, patented in England in 1844, Mazeline press, Stevens press, manufactured by the Uskside Engineering Company.

(b) The following machines are of the double compression type of press:

Conffinhal-Bietrix machine.
Robert Middleton press.
Yeadons Double-Compression press.
Roux-Veillon press.
Johnson Briquet machine.

The following American presses are also of this type:

Renfrow Briquet machine.
Misner press.

Class III. Tangential or rotary briquet presses. This class may be divided into

(a) Roll type of presses.

(b) Rotary-plunger machines.

(a) *Roll type of press.* This type of press consists of two rolls of the same diameter, which are geared together so that one turns with the other at the same surface speed. In the face of these rolls pockets are arranged so that the pockets on each roll register perfectly with the corresponding pocket on the other roll. The prepared material is fed to these rolls from a hopper over them, and the turning of the rolls briquets the material. These presses have large capacity and are simple to handle, but they are not suited to make briquets weighing more than five or six ounces, and require more binder than plunger machines to produce briquets of equal strength. They are especially adapted for making small sized briquets, and have been used in this country in at least two of the successful briquetting plants. These machines have the advantage over plunger machines of being continuous in action so that there is no lost motion. They make briquets of various shapes, the pillow shape being the most satisfactory.

The following presses are of this type:

Mashek press.
Mulheim and Zimmerman's press.
Fourquensberg's press.
Hall-Bjorling patent fuel machine.
Loiseau press.
Devillers press.
Chisholm, Boyd & White press.

(b) *The rotary-plunger type.* The distinguishing characteristic of this style of press consists in a series of plungers radially located in the rim of a wheel, some machines having only one ring and others having several rings of molds in the rim of the wheel.

This type of press has the valuable features of continuous action, no lost motion, and high capacity of the roll press, and the added advantage of being able to make briquets with less binder and greater coherence than the roll machine, and the size of the briquet that can be made

on this machine is greater than that possible with the roll type.

The following machines are of the rotary-plunger type:

Brogueaux press (France).

Ladley press, made by the National Pressed Fuel Co., of Indianapolis.

Schorr press, designated by Mr. Robert Schorr, a consulting engineer of San Francisco.

Hale Briquetting Machine, Standard Fuel Company, Birmingham, Ala.

ADVANTAGES OF BRIQUETTED FUEL.

Briquets, when properly made with a suitable binder possess the following advantages over raw fuel:

1. The even size of the briquets permits of a more regular and thorough combustion in the fire box or furnace, as the spaces that exist between adjacent blocks allow of even distribution of air through the fire and the pressure drop through the fire is also less.

2. A good briquet holds its shape in the fire so that even when coking coals are used they do not coke together sufficiently to cut off the air for combustion, and the gases are burned as fast as distilled off, so that

3. Practically no smoke should be obtained from the combustion of good briquets.

4. Briquets generally burn to a fine ash rather than a clinker, as in the briquetting process the mixing and grinding thoroughly distribute the ash material, which in the raw fuel exists in spots and layers, and are fused into clinker instead of falling through the grate.

5. The characteristic fineness of the ash from briquets allows of keeping a better fire with less attention and poking than is possible with raw fuel under the same conditions.

6. The evaporation per pound of fuel is greater for the briquetted than for the same coal in its natural state.

This advantage is maintained at all rates of evaporation.[1]

7. The capacity of a boiler is considerably increased by the use of briquetted fuel.[1]

8. The weather resisting qualities of many coals, and especially lignites, are greatly improved by briquetting.

9. Briquets apparently give a longer flame than run-of-mine coal.[2]

10. It is much easier to raise and to keep up steam with briquets than with run-of-mine coal.[3]

11. Higher rates of combustion are possible with briquets and consequently higher power.[3]

12. When properly made there is less loss from breakage during transportation of briquets than of run-of-mine coal.

13. The danger of spontaneous combustion in storage piles is eliminated if the fuel is stored in the briquetted form, and this characteristic of briquets has made briquetted fuel favored for storage by European countries.

14. The block shaped briquets may be piled in regular piles and occupy less space than the run-of-mine or slack from which they were made.

15. Briquets, especially those made from lignite, have a higher heat value than the raw fuel from which they were made, this improvement resulting from the higher heat values of the binder added to bituminous and anthracite coal to briquet them, and from the evaporation of water from the raw lignite in the case of lignite briquets.

While the United States has been more fortunate in the amount of good bituminous and anthracite coal which it possesses than European countries, still the time is not far distant when our people must realize that if the price of coal is not to reach such a high figure that our indus-

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[1] Goss, W. F. M., in U. S. G. S. Bull. No. 363, "Comparative Tests of Run-of-mine and Briquetted Coal on Locomotives."

[2] Ray & Kreisinger, U. S. G. S. Bulletin No. 403, "Comparative Tests of Run-of-mine and Briquetted Coal on the Torpedo Boat Biddle."

[3] Ray & Kreisinger, U. S. G. S. Bulletin No. 412, "Tests of Run-of-mine and Briquetted Coal in a Locomotive Boiler."

tries cannot compete with foreign industries, we will have to be more careful of what is now wasted in the process of mining, and then we may look for the general adoption of briquetting as a partial solution of the problem of mine waste.

FIRE TESTS ON SAND-LIME BRICK.

BY

T. R. ERNEST, Champaign, Ills.

INTRODUCTION.

The effect of heat on sand-lime brick is a question which has been of vital interest to the manufacturers of brick, both sand-lime and clay, for more than a decade. Buildings will burn occasionally, and after the fire the condition of the remaining walls of a brick building is of no little consequence. Many opinions have been expressed on this subject, and the literature is full of reports of the good behavior of sand-lime brick in conflagrations. Some experiments have also been carried out along scientific lines with a view to determining the effect of heat on this material, but nothing of very great significance has been reported thus far.

The fact that sand-lime brick is a mass of sand grains cemented together by a bonding material of hydrated calcium silicate leads one too suppose that, on heating, no very great change will occur until a temperature is reached sufficiently high to expel the combined water, and that when this has been driven out there will remain only a mass of sand, lime, and finely-divided silica, and that on further heating a point will finally be reached where lime and silica can combine to form for the sand grains a new bond of anhydrous calcium silicate. The result of this combination or vitrification is, of course, a silica brick.

This work was undertaken for the purpose of establishing the truth or falsity of these assumptions, also to determine, if possible, the temperature at which dehydration takes place and to study the effect of various degrees of heat upon the crushing and transverse breaking strengths of sand-lime brick.

DESCRIPTION OF EXPERIMENT.

Materials: The materials used for these tests were two brands of commercial sand-lime brick sent at our request by the manufacturers. There could have been no selection by the makers other than to exclude any that were chipped which would, of course, be highly desirable. More bricks were ordered than were actually required for each test, so that all those damaged in any way might be discarded.

Apparatus: The kiln used for burning is one belonging to the Department of Ceramics of the University of Illinois. It has a capacity such that it will easily hold 150 brick, and is of the down-draught type. The fire gases pass below and up the back, then down through the ware, up the front, and over the top to the flue. Connellsville coke was used for fuel, and temperatures were measured by the us of a thermo-couple of the platinum-rhodium type. The couple was enclosed in a quartz glass tube, which was inserted into a fire clay tube set in the kiln. For the purpose of measuring the crushing and cross-breaking strengths, two 100,000 pound Riehle testing machines, belonging to the Laboratory of Applied Mechanics, were used. These are exactly alike, except that, on the slow speed, the one advances at the rate of $\frac{1}{5}$ inch per minute, while the other is geared to move only 1-10 inch per minute. The latter of these was used for the transverse tests.

Procedure: (a) In burning: The procedure in burning was as follows: The brick were set in the kiln, the fire-clay pyrometer tube put in place, and a wicket built up on the evening preceding the experiment. The fire was started and about three or four hours taken to bring the temperature up to 300°, at which temperature the first draw was made. The heat was then slowly increased and drawings of 11 brick were made at each 100° rise in temperature, until the maximum was reached. About 20 hours were required for each burn. When drawn, the brick were allowed to cool, then marked and carefully packed so as not

to be injured in being removed to the Laboratory of Applied Mechanics, where tests were made.

(b) In Testing: These tests were made according to the latest specifications of the American Society for Testing Materials,[1] which read, in part, as follows:

> "**Transverse Test.**—At least five bricks shall be tested, laid flatwise with a span of 7 inches, and with the load applied at middle span. The knife edges shall be slightly curved in the direction of their length. Steel bearing plates, about ½ inch thick and 1½ inches, wide, may be placed between the knife edges and the brick. The use of a wooden base-block, slightly rounded transversely across its top, upon which to rest the lower knife edges, is recommended. The modulus of rupture shall be obtained by the following formula:
>
> $$R = \frac{3\ We}{2\ bd^2}$$
>
> in which e is the distance between supports in inches, b is the breadth and d the depth of the brick in inches, W is the load in pounds at which the brick failed.
>
> **Compression Test.**—Compression tests shall be made on half bricks resulting from the transverse tests. The bricks shall be bedded flatwise on blotting paper, heavy fibrous building paper, or felt, to secure a uniform bearing in the testing machine. The machine used for compression tests shall be equipped with spherical bearing blocks. The breaking load shall be divided by the area in compression, and the results reported in pounds per square inch."

Method of Averaging Results: The result of each individual test was recorded, but before taking the mean, one out of every eleven was discarded. The object was, of course, to eliminate any test that was noticeably out of accord with the others. In the case of the transverse tests there were several instances in which more than 10 per cent had to b discarded before taking the mean. In the unburned condition, tests were made on 22 bricks in each series.

[1] Report of Committee at Atlantic City Meeting, July, 1909: Published in Proceedings, Vol. IX.

RESULTS OF SERIES E.

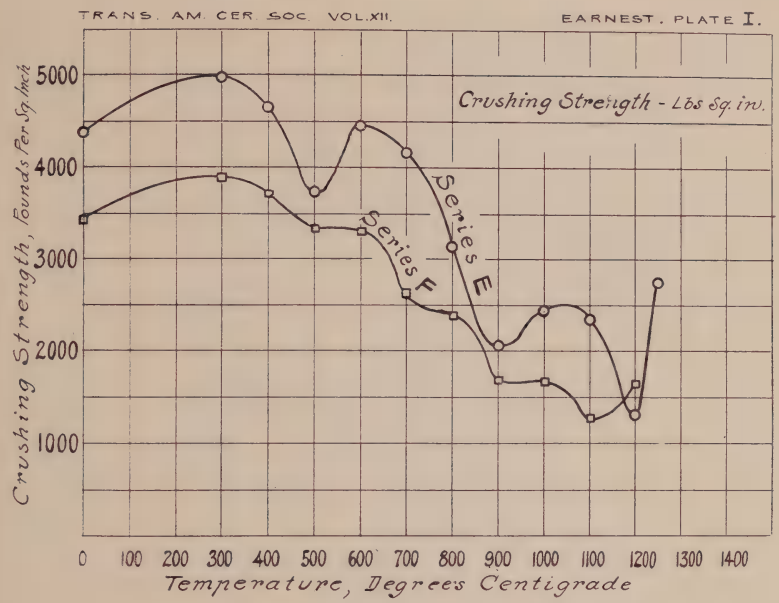
Series No.	Temperature Degrees C.	Modulus of Rupture	Compression lbs. per sq. in.
E	000	430	4382
E	300	238	4980
E	400	145	4650
E	500	95	3720
E	600	83	4440
E	700	68	4155
E	800	68	3130
E	900	33	2050
E	1000	33	2440
E	1100	26	2350
E	1200	47	1310
E	1250	74	2750
E	1370	554	3341

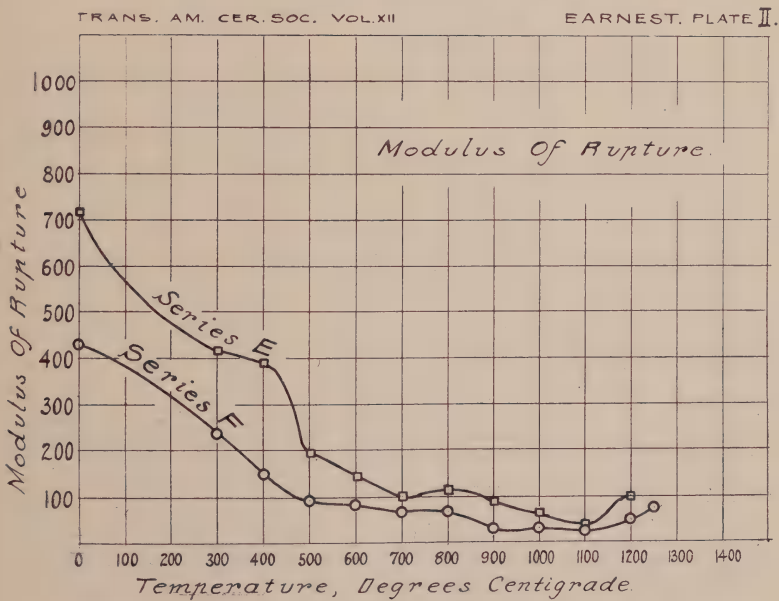
RESULTS OF SERIES F.

Series No.	Temperature Degrees C.	Modulus of Rupture	Compression lbs. per sq. in.
F	000	717	3430
F	300	418	3900
F	400	388	3710
F	500	197	3340
F	600	142	3320
F	700	100	2640
F	800	116	2400
F	900	85	1700
F	1000	61	1680
F	1100	37	1280
F	1200	101	1670
F	1370	157	4860

DISCUSSION OF RESULTS.

The results of this work are best shown graphically. In the plates, temperatures in degrees centigrade are represented as abscissae, while the ordinates represent pounds pressure. It will be noticed that the curves take the same general direction. The two curves in Plate I represent the crushing strength in pounds per square inch, while in Plate II the effect of heat on the modulus of rupture is shown. It will be noticed that the modulus of rupture falls off continuously until 1100° is reached, from which point it begins to increase. The curves representing com-


TRANS. AM. CER. SOC. VOL. XII.
EARNEST. PLATE I.
Crushing Strength - Lbs Sq. in.
Crushing Strength, Pounds Per Sq. Inch
5000
4000
3000
2000
1000
Series E
Series F
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
Temperature, Degrees Centigrade


TRANS. AM. CER. SOC. VOL. XII
EARNEST. PLATE II.
Modulus Of Rupture.
Modulus Of Rupture
1000
900
800
700
600
500
400
300
200
100
Series E
Series F
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
Temperature, Degrees Centigrade

pression ,on the other hand, show a marked increase at 300°. This can doubtless be explained on the supposition that, at this temperature, the brick are more thoroughly dried, and that any uncombined lime is changed to the carbonate by the fire gases. At 500° the curves have a minimum which has not, as yet, been satisfactorily explained, but which may be due to the breaking up of some hydrated calcium silicate with the subsequent formation of the corresponding carbonate. The minimum at 900° is probably due to the expulsion of CO_2 at this temperature. The final increase in both compression and transverse strengths is easily explained on the assumption that here there is a combination of lime and silica to form a bond of anhydrous calcium silicate. It is to be regretted that higher temperatures could not be reached; however, it is the intention to determine at least one other point in the neighborhood of 1300° C.[1]

The results of this work show that in compression strength sand-lime brick will be damaged but little by any ordinary conflagration. The transverse tests, however, show that the depreciation is very nearly proportional to the temperature, especially for low temperatures. It may be said in favor of sand-lime, however, that in all the specimens tested there was not a sign of warping or shrinkage at even the highest temperatures, and that at these temperatures the brick had a very pleasing appearance, resembling very much a high grade buff face brick. Some specimens were cracked badly, and in nearly every instance of this kind there was found a lump of lime, in some cases of quite considerable size, which doubtless explained it. In transverse strength, the unburned brick and those heated to the highest temperature broke with a snap; at all other temperatures the failure could be detected only by the drop in the scale beam, and in many cases the two halves hung together with quite a little tenacity. At the highest tem-

[1] Determinations at 1370 degrees made later by the author and inserted in table of results by the editor, but not in curve sheets.

peratures reached, and also at 500° in the case of one series, the specimens failed in compression with a crashing sound, resembling in this respect a vitrified clay brick.

CONCLUSION.

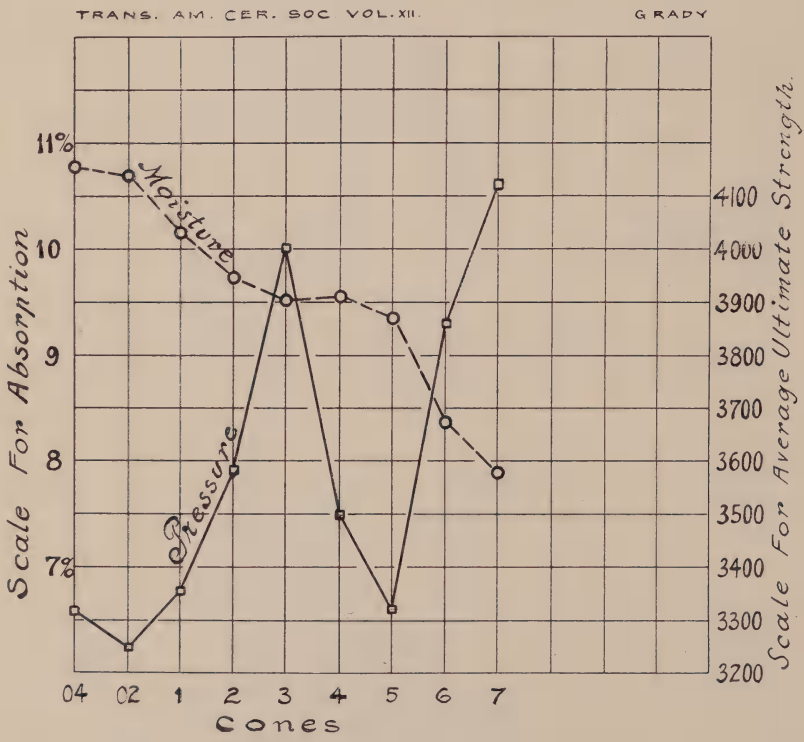
It has been shown that the effect of fire on the strength of sand-lime brick is a function of the temperature reached. A case can hardly be imagined where, in a conflagration, the temperature would go high enough to result in the formation of a true silica brick; so that in considering this material from the standpoint of its ability to pass with immunity through conflagrations, only the first halves of the curves need to be considered. In any final conclusion as to the relative merits of sand-lime as compared with other brick, it must be remembered that strength is but one of the many properties to be considered, and that in the matter of conductivity, shrinkage, coefficient of expansion, warping, etc., sand-lime is in a class by itself.

RELATION OF ABSORPTION TO THE CRUSHING STRENGTH OF TERRA COTTA.

BY

R. F. GRADY, St. Louis, Mo.

In former experiments made by the writer to determine the crushing strength of terra cotta, results of which are published in Vols. X and XI of the Transactions of



the American Ceramic Society, no attempt was made to show what effect absorption would have on the strength of

the material. The experiments set forth in the following table were made to determine what this effect was.

The test cubes were all made of the same mixture of light buff-burning clay, and were all set in a small kiln and heated up to cone 04, when four cubes were drawn and put in another small muffle heated to cone 04 and held at that heat. When cone 02 fell four more cubes were drawn and put in muffle. This was continued until all except four cubes were drawn at cone 6 down. These were left in kiln until it cooled.

The curves of the moisture shown on cross section sheet herewith shows a fairly uniform decrease in absorption as the greater heats were reached. The pressure curve indicats no such regularity.

Plaster caps were put on all cubes before breaking them, and it is the opinion of the write that if opposite faces had been ground parallel more uniform results would have resulted.

No.	Heat Attained in Cones	Dry Weight in Grams of Burnt Cubes	Wt. in Grams of Cubes after lying in Water 24 Hours	Wt. in Grams of Water Absorbed	Per Cent. of Water Absorbed	Average % of Absorption	Size of Cubes	First Crack	Ultimate Strength in Pounds	Average for Each Cone
1	Cone 04	272.0	301.5	29.5	10.84	10.85	2″x2″2″	8800	12270	3319.
2		275.0	305.0	30.0	10.91		" "	10500	12540	
3		271.0	300.0	29.0	10.70		" "	.....	14780	
4		274.0	304.0	30.0	10.95		" "	12500	13520	
5	Cone 02	276.0	305.5	29.5	10.69	10.73	" "	13500	13830	3248.
6		273.0	302.5	29.5	10.81		" "	.....	12470	
7		275.0	304.0	29.0	10.55		" "	11600	12590	
8		272.0	301.5	29.5	10.85		" "	12000	13080	
9	Cone 1.	277.0	304.0	27.0	9.75	10.16	" "	7800	13500	3354.
10		270.0	298.0	28.0	10.37		" "	.....	13970	
11		275.0	304.0	29.0	10.55		" "	13200	13720	
12		271.0	298.0	27.0	9.96		" "	10800	12460	
13	Cone 2.	275.5	302.0	26.5	9.62	9.76	" "	14900	15880	3585.
14		269.0	295.5	26.5	9.85		" "	11000	11850	
15		275.0	302.0	27.0	9.82		" "	.....	14710	
16		272.0	298.5	26.5	9.74		" "	12800	14920	
17	Cone 3.	275.0	302.0	27.0	9.82	9.55	" "	18000	18640	4007.
18		275.0	302.0	27.0	9.82		" "	15000	15750	
19		271.0	296.0	25.0	9.23		" "	14500	15110	
20		273.0	298.5	25.5	9.34		" "	11000	14610	
21	Cone 4.	275.0	301.0	26.0	9.45	9.60	" "	.....	14170	3499.
22		277.0	304.5	27.5	9.93		" "	12900	13480	
23		273.0	299.5	26.5	9.71		" "	9500	12680	
24		274.0	299.5	25.5	9.31		" "	14200	15650	
25	Cone 5.	273.0	298.5	25.5	9.34	9.36	" "	.....	15340	3320.
26		267.0	291.5	24.5	9.18		" "	8500	9830	
27		271.0	297.5	26.5	9.78		" "	9800	11480	
28		273.0	298.0	25.0	9.15		" "	16200	16470	
29	Cone 6.	279.0	302.0	23.0	8.24	8.37	" "	.....	15850	3867.
30		273.0	296.0	23.0	8.42		" "	17000	17940	
31		273.0	295.5	22.5	8.24		" "	13000	14180	
32		268.0	291.0	23.0	8.58		" "	13000	13900	
33	Cone 6. Not drawn	275.5	297.5	22.0	7.98	7.91	" "	16200	17440	4132.
34		272.0	293.0	21.0	7.72		" "	15000	15640	
35		272.0	293.5	21.5	7.98		" "	.....	19730	
36		276.0	298.0	22.0	7.97		" "	12200	13300	

KILN TEMPERATURES FROM COAL AND PRODUCER GAS.

BY

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The calculations embodied in this paper were primarily made for our own information to enable us to answer numerous questions in regard to the use of producer gas.

These questions came not only from the brickmaker who had no knowledge of the subject, but also from the builders of gas producers and from the professional engineer.

We had no intention of putting the results in the form of a paper, and only did so at the request of the Secretary, who must assume all responsibility. The paper is purely hack work and there is nothing original in it, but it may serve its purpose of answering questions in regard to producer gas and the value of the same compared with coal fired direct.

The data of the fuels are taken from the United States Geological Survey, "Report on Coal Tests," Professional Paper No. 48.

The method of calculation is that used by E. Damour in his book "Industrial Furnaces," the translation being by A. L. Queneau.

From this book we take the following table used in the calculations:

TABLE I.

Thermo-Chemical Reactions.

SUBSTANCE	Molecular Formula	Molecular Weight	Molecular Volume	REACTIONS	Liberated Calories per Molecular Volume
		Grams	Litres		
Hydrogen	H_2	2	22.32	$H_2+\frac{1}{2}O_2=H_2O$	058.2*
Carbon	C_2	24	.....	$\frac{1}{2}C_2+O_2=CO_2$	097.6
Carbon	C_2	24	.....	$\frac{1}{2}C_2+\frac{1}{2}O_2=CO$	029.4
Carbon-monoxide	CO	28	22.32	$CO+\frac{1}{2}O_2=CO_2$	068.2
Methane	CH_4	16	22.32	$CH_4+2O_2=CO_2+2H_2O$	195.2*

*Water as vapor.

We have only taken that part of the table which is used in our calculations, and for the complete table reference is had to the above mentioned book.

In the hydrogen and hydro-carbon gases the water resulting from combustion is considered as vapor and the calories taken accordingly. If the resulting water vapor passes into water, the resulting calories would be increased by the latent heat in the water vapor, but in kiln work any moisture entering the furnaces will be converted into vapor and remain as such until expelled from the kiln. Therefore our calculations will be on this basis.

The following table also taken from "Industrial Furnaces," gives the "Thermal Capacity of Gases per Molecular Volume," or in other words it gives the number of calories that will be required to raise unit volumes of the combustion gases to the several temperatures shown in the table.

TABLE II.

Thermal Capacity of Gases per Molecular Volume.

Temperatures	O_2, N_2, H_2, CO	H_2O	CO_2	CH_4
0°C	00.00	00.00	00.00	00.00
200°	1.39	1.73	1.85	2.19
800°	5.82	8.23	9.18	11.46
1000°	7.43	10.98	12.22	15.77
1200°	9.05	13.87	15.55	20.37
1400°	10.73	17.00	19.18	25.44
1600°	12.46	20.35	23.10	30.99
1800°	14.21	23.86	27.21	36.86

With these two tables the heat calculation becomes quite simple though tedious.

The following example, using Texas Coal No. 2, will illustrate the method of calculation:

Coal — Ultimate Analysis		Producer Gas — By Volume	
H_2	6.79	CO_2	9.60
C_2	42.52	CO	18.22
N_2	.79	O_2	.20
S_2	.53	N_2	57.53
O_2	42.09	H_2	9.63
Ash	7.28	CH_4	4.81
	100.00		99.99

The coal analysis in every case is that corrected to sample as received by the Survey, and in the majority of cases is the car sample.

The producer gas given in the Survey report, being for engine use, was cooled, scrubbed, etc., and does not represent the gas as it comes from the producer and as we would use it in kiln work, particularly in moisture content.

We have therefore corrected the gas analysis for moisture, using the data given in the same report wherein the cubic feet of gas from coal as fired and from dry coal is given.

For instance, in the Texas No. 2 coal we find that each

pound of coal as fired gave 34.2 cu. ft. of gas, while dry coal gave 51.6 cu. ft. of gas. From these figures we determine that the gas as it came from the producer should have 33.72% of moisture, which happens to be the actual percent of moisture in the coal as shown by the proximate analysis.

Correcting the gas analysis to introduce this moisture we get the following composition for the producer gas:

(We have at the same time reduced the analysis to one volume for the purpose of our calculation.)

CO_2	.0636
CO	.1208
O_2	.0013
H_2	.0638
N_2	.3813
CH_4	.0319
H_2O	.3372
	.9999

The available calories are figured as follows:

	Calories Available as Latent Heat	Calories as Sensible Heat. Temperature 100° C. Assumed
.121 vol. CO × 68.2	8.25	...
.064 vol. H_2 × 58.2	3.72	...
.032 vol. CH_4 × 195.2	6.25	...
.064 $CO_2 \times \frac{1.85}{2}$	....	.06
.121 CO	....	...
.001 O_2	....	...
.064 H_2	....	...
.381 N_2	....	...
.567 $\times \frac{1.39}{2}$	....	.39
.032 $CH_4 \times \frac{2.19}{2}$	....	.04
.337 $H_2O \times \frac{1.73}{2}$	....	.29
Available Calories	18.22	.78
Total		19.00

We have assumed that the gases enter the furnace at 100°C. or higher temperatures, in order to maintain the water as vapor.

This calculation gives us the total calories which can be obtained from combustion of one volume of gas, including the sensible heat carried in by the gas.

If we wish to introduce any radiation loss, we deduct the percent of loss from the above total available calories.

We next determine the oxygen requirements as follows:

CO requires one half vol	.060
H_2 requires one half vol	.032
CH_4 requires two vols	.064
Total oxygen	.156
Less oxygen in gas	.001
Oxygen required	.155
Multiply by 3.8 (N_2)	.590
Total air required	.745

Add to this, or rather determine it as a separate item, whatever air excess we wish to introduce.

We now have to determine the thermal consumption of the products of combustion, using for this purpose Table II, which gives the thermal capacities for various temperatures.

This calculation is as follows:

		1200°	1400°
From CO_2	=.064		
From CO	=.121		
From CH_4	=.032		
Total CO_2	=.217 × {15.55 / 19.18	3.37	4.16
From N_2	=.381		
From Air	=.590		
From Air Excess			
Total N_2 and Air	.971 × {9.05 / 10.73	8.79	10.42
From H_2	=.064		
From CH_4	=.064		
From H_2O	=.337		
Total H_2O	=.465 × {13.87 / 17.00	6.45	7.91
		18.61	22.49

It is evident that with 19.00 available calories as found, the heat absorption of the products of combustion will permit a kiln temperature of between 1200 and 1400 degrees,—nearer the former. The determination of the actual temperature from these figures is only a matter of simple arithmetic.

If we consider radiation losses, we must reduce the available calories accordingly, and if we introduce any air excess we increase the heat consumption of the waste gases,—both of these elements tending to lower the possible kiln temperature.

The calculations for the coal follow practically the same lines, but in this case we are dealing with weights instead of volumes of gas.

We made two sets of calculations for the coal,—finding that our first calculation introduced a serious error.

In our first determinations we took the calories of the coal as determined by the survey for the available calories.

Then we determined the products of combustion as follows:

$\frac{42.52\ C_2}{12}$ gives 3.540 Vols. CO_2

$\frac{6.79\ H_2}{2}$ gives 3.390 Vols. H_2O

$\frac{.79\ N_2}{28}$ gives 0.028 Vols. N_2

$\frac{42.09\ O_2}{32}$ gives 1.310 Vols. O_2

OXYGEN REQUIREMENT.

For CO_2	3.54	
For H_2O	1.69	
Total	5.23	
Less Oxygen in Coal	1.31	
Total Oxygen	3.92	
Multiply × 3.8	14.92	(Nitrogen)
Total Air	18.84	

We have now only to determine the thermal consumption as follows:

			1800°	2000°
CO_2	$= 3.54 \times$	$\begin{cases} 27.21 \\ 31.84 \end{cases}$	96.32	112.71
N_2	$= 14.92$			
N_2 in Coal	.028			
Air Excess	.....			
	$14.95 \times$	$\begin{cases} 14.21 \\ 16.05 \end{cases}$	212.44	239.95
H_2O	$= 3.39 \times$	$\begin{cases} 23.86 \\ 27.76 \end{cases}$	80.89	94.11
			389.65	446.77

The calorific value as given by the survey is 4082, or for one hundred grams, which is the basis of our calculation, 408.2.

We immediately see that the possible kiln temperature under perfect combustion, with no radiation loss, will be between 1800 and 2000 degrees C.

The error which this method introduced comes from the fact that the calories as determined by the Survey include the latent heat of the water vapor, since the gases are cooled below the dew point, while in our kiln temperatures the moisture remains as vapor. To correct this error and get nearer the truth, we had to calculate the available calories direct from the ultimate analysis. To do this it became necessary to eliminate the oxidized elements, since they would not be available for any combustion. We have assumed that all the oxygen in the ultimate analysis is in combination with hydrogen. This may not be true, but we know that a large part of the oxygen represents moisture, and any remaining oxygen represents oxidized elements, and we are not introducing any large error in assuming that all the oxygen is combined with hydrogen.

Our calculation for available calories then becomes as follows:

1.31 vols. O_2 will form 2.62 vols. H_2O.

This from 3.39 leaves .77 volumes H_2O, in which the hydrogen is available for combustion. 3.54 volumes CO_2 is the equivalent of the same volume of carbon, and .77 volumes H_2O represent .77 volumes of H_2.

Our calculation becomes as follows:

$3.54 \times 97.6 = 345.5$
$0.77 \times 58.2 = 044.8$

390.3 Available Calories

against 408.2 as determined by the Survey.

The thermal consumption will be the same in either case, and it will be seen that the possible temperature from this coal under perfect combustion and with no radiation loss, will be slightly above 1800 degrees C.

The elements which affect kiln temperatures besides

the calorific value of the fuel and the thermal requirement of the products of combustion, are radiation losses and excess air to insure complete combustion. Perhaps we should also include moisture, although this properly belongs with the fuel calculation except in cases where extraneous water is introduced by wetting the fuel, as is often done, or by introducing steam to form water gas.

It is not our intention to take up this question of water introduction. Our Table III will show that the addition of water as water will lower the possible kiln temperature.

It may be said that the use of steam to form water gas may, under certain conditions, give a higher kiln temperature than can be obtained from the coal alone. We do not wish to be understood that any calorific value can be had from the use of steam. It introduces no calories except the latent heat, which is insignificant, and consequently can develop no calories. But it may change the relation between the available calories and the thermal requirements of the products of combustion, so that a higher temperature becomes possible.

Carbonic oxide has a higher calorific intensity than carbon and carbon higher than hydrogen under conditions of perfect combustion. Carbonic oxide and hydrogen each require one half volume of oxygen for combustion, while carbon requires one volume.

Now if we are introducing thirty to fifty percent excess of air, necessary for perfect combustion, we introduce twice as much for carbon as we do for either carbonic oxide or hydrogen, and this double volume of excess air reduces the calorific intensity that can be had from the carbon, and carbon ranks below hydrogen as well as below carbonic oxide. In other words, we can perfectly burn carbonic oxide and hydrogen with less excess of air than would be necessary to burn carbon, and this lower excess of air will enable us to get a higher kiln temperature with the same total calories.

TABLE III.

Kiln Temperatures from Producer Gas, Texas Lignite No. 2. In ° Centigrade.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		100 per cent. Air. Air Cold. No Radiation loss.	100 per cent Air. Air Cold. 10% Radiation Loss.	100 per cent. Air. Air Cold. 20% Radiation Loss.	125 per cent. Air. Air 1000°. No Radiation Loss.	125 per cent. Air. Air Cold. No Radiation Loss.	125 per cent. Air. Air 1000°. 10 Radiation Loss.	125 per cent. Air. Air Cold. 10% Radiation Loss.	125 per cent. Air. Air 1000°. 20% Radiation Loss.	125 per cent. Air. Air 1000°. 20% Radiation Loss.	200 per cent. Air. Air 1000°. No Radiation Loss.	200 per cent. Air. Air Cold. No Radiation Loss.	200 per cent. Air. Air Cold. No Radiation Loss.	200 per cent. Air. Air Cold. 10% Radiation Loss.	200 per cent. Air. Air 1000°. 20% Radiation Loss.	200 per cent. Air. Air Cold. 20% Radiation Loss.
1	Cold Gas No Moisture	1497	1375	1260	1784	1363	1635	1248	1484	1085	1612	1071	1476	987	1204	878
2	500° Gas 10% Moisture	1606	1461	1325	1847	1466	1692	1336	1535	1215	1672	1176	1533	1070	1389	963
3	100° Gas 10% Moisture	1444	1325	1203	1716	1330	1570	1216	1429	1110	1572	1058	1439	965	1305	863
4	500° Gas 20% Moisture	1519	1404	1265	1760	1406	1615	1305	1467	1204	1615	1138	1480	1040	1338	938
5	100° Gas 20% Moisture	1366	1250	1135	1623	1286	1489	1191	1356	1100	1505	1016	1375	935	1249	830
6	500° Gas 30% Moisture	1425	1309	1190	1657	1329	1521	1215	1382	1100	1541	1093	1413	998	1281	902
7	100° Gas 30% Moisture	1260	1150	1153	1507	1175	1385	1066	1256	940	1419	960	1298	874	1170	792
8	500° Gas 40% Moisture	1334	1225	1090	1547	1249	1425	1145	1291	1037	1458	1047	1335	957	1212	866
9	100° Gas 40% Moisture	1152	1050	956	1387	1085	1280	990	1155	905	1320	896	1211	820	1093	742
10	500° Gas 50% Moisture	1231	1130	1026	1429	1162	1312	1065	1193	965	1364	995	1251	909	1134	823
11	100° Gas 50% Moisture	1025	946	855	1248	972	1151	888	1040	810	1214	827	1109	756	1105	683

In discussing kiln temperatures it would be pertinent to consider the size and character of furnaces, draft, etc., but these are mechanical features and theoretically are without effect.

One pound of coal will have the same flame temperature as a thousand pounds, and will heat a kiln to the same temperature if there are no losses of heat. When, however, we consider the radiation losses, then the volume of fuel cuts a large figure. If we are firing one hundred pounds per hour and the radiation loss is one hundred pounds for the same period, we can get no kiln temperature whatever, because the radiation loss is 100%. If we fire two hundred pounds per hour the radiation loss is only 50% and we have some fuel available for kiln temperatures. Four hundred pounds per hour reduces the radiation loss to 25% plus, of course, any additional radiation loss on account of the increased kiln temperature.

The furnace problem is therefore included in the radiation.

We have seen kilns which required all the skill and ingenuity of the burner and considerable time to get the required heat in the kiln, simply because the furnace power was insufficient, and the heat generated in the furnaces was carried away by radiation. We have had instances in our experience when it was necessary to daub up the sides of the kiln and cover the crown with clay in order to get the desired temperature. We had one instance where it was simply impossible to get the heat to the desired temperature on account of lack of furnace power, or rather excessive percentage of radiation.

Radiation loss is a fixed factor for each temperature and should be measured in pounds of fuel rather than in percents. Six furnaces may bring up the temperature of a kiln until radiation loss prevents further advance. If a seventh furnace is put on, none of its fuel is required to maintain the radiation loss, and the calories produced are available to increaes the temperature until the increased

radiation loss calls a halt. An eighth furnace will still further advance the temperature, and so on until the full practical value of the fuel is obtained in kiln temperatures. The radiation loss in pounds of fuel is increasing with the advancing temperatures, but in percent is decreasing as each additional furnace is put on.

We recall a remark made to us by a member of this Society several years ago, to the effect that if he could he would have a solid ring of fire around his kiln.

American kiln construction practice is very chary of furnace power and we need to overhaul our designs in this respect, and the result will be quicker burns and a decided saving in fuel on many yards.

There is no data from which we can accurately figure the radiation losses of kilns, but we are inclined to think they are much greater than usually estimated. If this could be investigated and brought to the attention of clay workers, it would undoubtedly lead to better kiln construction.

In Prof. Bleininger's paper, "A Study of Heat Distribution in Four Industrial Kilns," published in Vol. X, Am. Cer. Soc. Trans., the heat losses taken up by the kilns and lost by radiation were as follows:

Round down draft brick kiln	49.61%
Terra Cotta muffle kiln	33.30
Round down-draft paving brick kiln	54.90
Terra Cotta muffle kiln	59.73
Rectangular sewer pipe kiln	71.10

Average loss for each kiln, 53.7%.

An average down draft kiln will require about one hundred thousand bricks to build. The internal temperature in the above kilns was about 1100 deg. C., and if we assume that the outside wall temperature was 200 degrees, we get an average wall temperature of 650 degrees.

$$\frac{100{,}000 \text{ (brick in kiln)} \times 6 \text{ (wt. of bricks)} \times .2 \text{ (sp. ht.)} \times 650 \text{ (temp.)}}{2.2 \text{ (to reduce to kilograms)}}$$

$= 3{,}550{,}000$ calories absorbed by the kiln.

The total fuel charged to the kilns and radiation losses, averages 248,000,000 calories per kiln. From these figures we find that about one and one half percent was taken up by the kiln walls, leaving over 50% to be accounted for by radiation.

A recent article in Tonindustrie-Zeitung gives a radiation loss of 32% for a continuous kiln.

These figures are startling, and if we were to accept them without qualification, our calculations would show that it would be impossible to get temperatures required for ceramic work from any fuel. We could get practically flame temperatures in the furnaces, but in the crown of the down draft kiln the radiation loss would be heavy and rapidly cool down the combustion gases, and this cooling process would continue in greater or less degree to the bottom of the kiln. In figuring possible kiln temperatures we take the coolest part of the kiln.

It must be remembered that radiation loss is a factor of the kiln and the temperature and not a factor of the fuel. It should not be figured in percent of the fuel, but in pounds of fuel, and is a fixed quantity for each temperature.

To get higher kiln temperatures, it becomes necessary to increase the fuel consumption in the furnaces at a greater rate than will be required to provide for the increasing radiation loss, or in other words to lower the percent of radiation loss. While the total radiation loss may be 50%, yet when we are getting the finishing heats in our kilns we are burning fuel at such a rate that the radiation loss is much less than 50% for the time being. We have assumed a radiation loss of 20% in our calculations of kiln temperatures.

Excess air lowers the kiln temperature simply by using up available calories in being heated to the kiln temperature. It brings no calories into the kiln, and on the contrary takes a good many out.

The ash of a coal is a factor which does not enter into

the theoretical consideration of available kiln temperatures. A coal might contain fifty percent of ash and yet give the same kiln temperature as an absolutely pure coal, since it is only necessary to burn two pounds of it to get the same value as from one pound of pure coal. While ash does not affect the calorific intensity, it is an important matter in calorific value, and all coals should be bought on the basis of the calories contained in them. From a purely practical standpoint, the high ash content may affect kiln temperatures, since it is more difficult to burn such coals and keep within the minimum allowance of excess air, and the heat lost in rustling and cleaning the fires must be taken into account.

In Table III we have taken the producer gas analysis of Texas No. 2 coal without making any corrections for moisture, and it shows the temperatures which can be obtained from this gas under varying conditions. The first line shows temperatures from cold gas with no moisture, and the subsequent lines are for gas heated to 500 and 100 degrees respectively, and at the same time introducing increasing percentages of moisture. The 500 degree gas temperatures show the advantage of taking the gas hot from the producer and thus saving the initial heat. It may be remarked that there is a distinct advantage in working the producer hot, not because of the initial heat alone, but the hotter the producer, up to a thousand degrees, the higher will be the percentage of CO. It is said that the tendency of CO to crack and deposit carbon with resulting CO_2 is greater, the lower the temperature, but at 1000 degrees the tendency is practically nil. If this is true, then producer gas for ceramic work will show up much better if worked hot, and the producer is so placed that the initial heat may be saved. We do not know what practical difficulties may be in the way of working the producer hot.

The vertical columns show varying percentages of air from that required for perfect combustion to that of 100% excess, the air being alternately cold and heated to 1000 degrees, and radiation losses from nothing to 20%.

The first three columns have no excess air, and if the gas can be perfectly burned under these conditions, and the radiation loss does not exceed 20%, we can get the temperatures given in column 3, which are around cone 1.

Gas has the advantage over coal in that greater volumes of it can be burned in a given time, thus reducing the percent of radiation loss, but even then, we cannot get the temperatures which are obtained from the coal fired direct.

Fired under the same conditions as the coal, the gas gives a much lower temperature. We doubt if it is practicable to burn the gas with the theoretical amount of air which would rule out the first three columns, and it is still more doubtful if the radiation loss can be kept below 20%, which rules out all columns up to 8. Columns 8 and 9, it seems to us, would be commercial conditions, and with 30% of moisture which this particular coal contains, the possible temperatures would be less than cone 1 even though we save the 500 degrees of initial heat.

In continuous kiln work we could perhaps get the conditions in column 6 which would give very satisfactory temperatures, but these temperatures are lower than could be had from coal under the same conditions, as will be seen by referring to column 3 in Table IV, in which the air excess is 50% instead of 25%.

If columns 8 and 9 in Table III are commercial conditions, column 8 would apply to continuous kilns since the air is always preheated, and column 9 would apply to periodic kilns.

With a coal containing 30% moisture, we could get a temperature of 1382 in the continuous kiln and 940 in a periodic kiln. A coal containing less moisture,—let us say 10%,—would give temperatures of 1535 and 1110 respectively.

This table was prepared some time ago without any thought of publishing it, but simply to enable us to answer some of the questions frequently asked, and we think it answers conclusively the inquiry in regard to the use of producer gas in periodic kilns.

It is impossible to get temperatures sufficiently high for ceramic work from producer gas burned in periodic kilns under ordinary commercial conditions.

TABLE IV.

Kiln Temperatures from Texas Lignite No. 2. In ° Centigrade.

		1	2	3	4	5	6	7	8
		100 per cent. Air Air 1000°	100 per cent. Air Air Cold	150 per cent. Air Air 1000°	150 per cent Air Air Cold	200 per cent. Air Air 1000°	200 per cent. Air Air Cold	250 per cent. Air Air 1000°	250 per cent. Air Air Cold
1	No Radiation.....	2335	1869	2051	1462	1867	1200	1730	1015
2	10% Radiation.....	2156	1714	1887	1337	1707	1095	1586	921
3	20% Radiation.....	1970	1557	1718	1211	1548	989	1433	830

Table IV gives the results of the calculations for the coal fired direct, but it may be noted that these results are somewhat high since we took the calories as determined by the Survey for our calculations which, as previously noted, gives results too high on account of the calories in the latent heat of the water vapor.

This has been corrected in Fig. 6.

We have made no calculations showing the fuel value of the gas compared with the coal, but it goes without saying that we cannot burn the fuel and keep it at the same time.

From one-third to one-half of the carbon in the coal is represented by carbonic dioxide in the gas, and the heat generated by this combustion appears as initial heat in the gas.

From one-half to two-thirds of the carbon becomes carbonic monoxide in the gas, and roughly one-third of the fuel value of the carbon therein is used up in this partial

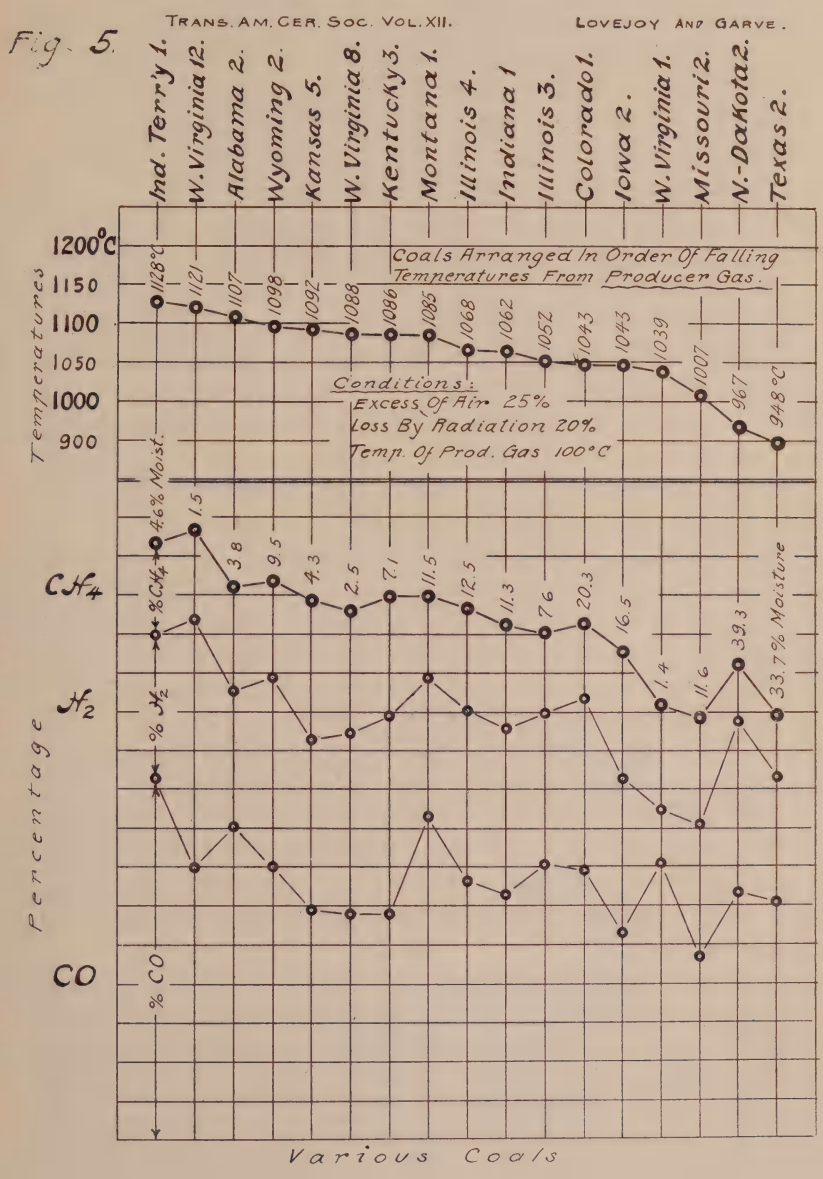


Fig. 5.
Trans. Am. Cer. Soc. Vol. XII.
Lovejoy and Garve.
Ind. Terry 1.
W. Virginia 12.
Alabama 2.
Wyoming 2.
Kansas 5.
W. Virginia 8.
Kentucky 3.
Montana 1.
Illinois 4.
Indiana 1
Illinois 3.
Colorado 1.
Iowa 2.
W. Virginia 1.
Missouri 2.
N.-Dakota 2.
Texas 2.
Temperatures
1200°C
1150
1100
1050
1000
900
Coals Arranged In Order Of Falling Temperatures From Producer Gas.
1128°C
1121
1107
1098
1092
1088
1086
1085
1068
1062
1052
1043
1043
1039
1007
967
948°C
Conditions:
Excess Of Air 25%
Loss By Radiation 20%
Temp. Of Prod. Gas 100°C
Percentage
4.6% Moist.
1.5
3.8
9.5
4.3
2.5
7.1
11.5
12.5
11.3
7.6
20.3
16.5
1.4
11.6
39.3
33.7% Moisture
CH4
% CH4
H2
% H2
CO
% CO
Various Coals

combustion and becomes initial heat. Thus perhaps fifty percent of the carbon in the coal becomes initial heat, and if we allow the gas to cool, all of this is lost. In addition to this there is the loss in deposited carbon due to the cracking of the gases, besides the tarry products.

This answers another inquiry that we get.

There is no economy in producer gas over direct coal firing considered from the fuel standpoint,—quite the contrary, there is a decided loss.

Satisfactory temperatures from producer gas can only be had in regenerative kilns, and the use of gas in any case will result in some loss of fuel over direct firing.

Better ware, better heat distribution, economical handling of coal and ash, are considerations which alone will warrant the use of producer gas.

Fig. 5 shows the producer gas kiln temperatures which can be had from seventeen coals given in the U. S. Report. These have all been corrected for moisture, as indicated in the beginning of this paper, and they are all figured on the basis of cold gas (100 degrees).

We have connected the points into a curve simply the better to follow them from point to point.

In this series we have assumed a radiation loss of 20% and an air excess of 25%.

The coals are arranged in the order of the temperatures obtained from the gases. The lower curves on the sheet show the percentages of CO, H_2 and CH_4, superimposed so that the upper line shows the total percentages of combustibles.

In this figure the Indian Territory coal ranks first, yet the total combustible gas is greater in West Virginia No. 12. The Indian Territory coal has a very high percentage of CO, which has a higher calorific value than either H_2 or CH_4. The others fall nicely into line except perhaps Montana No. 1, Illinois No. 3, Colorado No. 1, and North Dakota No. 2. Montana should perhaps have a higher rank but the moisture is rather high, which holds it down.

The low position of Colorado No. 1 is due to moisture, and likewise North Dakota No. 2. Illinois No. 3, it seems to us, should come above Illinois No. 4 and Indiana No. 1, and we cannot explain why it does not.

We consider the particular arrangement of the coals of small moment,—probably another set of tests would bring about a rearrangement in some measure, though the high moisture coals will necessarily occupy a low position. The feature of importance is that we cannot get high temperatures from cold producer gas burned with cold air.

Fig. 6 shows the values from the coals fired direct. The upper curve is the value from the coal based on the calories as determined by the Survey, and the values are too high by the latent heat of the water vapor, as previously explained. We discovered this when we plotted the values for carbon and hydrogen burned under the same conditions. A coal made up of hydrogen and carbon could not give a higher temperature than the pure elements or a mixture of them.

We also have put on this sheet the values from Fig. 5 in order to compare the producer gas values with the coal values, and the sheet also shows one coal calculated for various percentages of radiation loss.

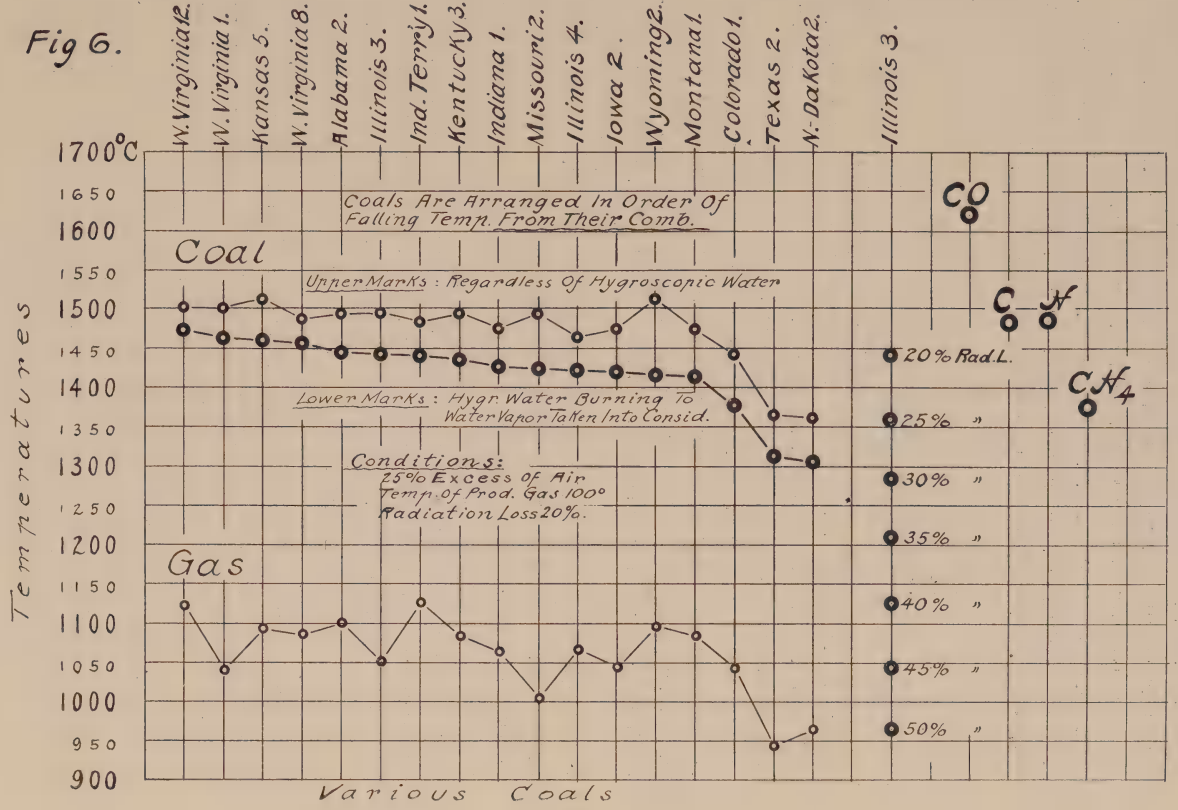
Regarding temperatures from C_2, CO, H_2, and CH_4, it will be noted that CO has the highest calorific intensity. The values for complete combustion with no radiation loss nor excess air are as follows:

CO	2140
C_2	2080
H_2	1970

As we introduce air on a percentage basis carbon gradually approaches and falls below hydrogen, and it happens in our calculations that with 25% excess air these two elements give practically the same temperature.

The falling off of the carbon value is due to the fact that carbon requires one volume of oxygen while hydrogen requires only one-half volume. This double volume of

Fig 6.


W. Virginia 12.
W. Virginia 1.
Kansas 5.
W. Virginia 8.
Alabama 2.
Illinois 3.
Ind. Terry. 1.
Kentucky 3.
Indiana 1.
Missouri 2.
Illinois 4.
Iowa 2.
Wyoming 2.
Montana 1.
Colorado 1.
Texas 2.
N. Dakota 2.
Illinois 3.
1700°C
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
Temperatures
Coals Are Arranged In Order Of Falling Temp. From Their Comb.
Coal
Upper Marks: Regardless Of Hygroscopic Water
Lower Marks: Hygr. Water Burning To Water Vapor Taken Into Consid.
Conditions:
25% Excess of Air
Temp. of Prod. Gas 100°
Radiation Loss 20%.
Gas
Various Coals
CO
C
N
CH4
20% Rad. L.
25% "
30% "
35% "
40% "
45% "
50% "

oxygen with its attendant nitrogen as the percent excess increases cuts down the calorific intensity of the carbon at a greater rate than that of the hydrogen.

In conclusion we wish to anticipate a question which has been confronting us. If the low temperatures which our calculations show for coal fired under commercial conditions are correct, and it is possible that the radiation loss may be much greater than we have estimated, how is it possible for the manufacturers of silica bricks to burn their product to cone 26 in the bottom of down-draft kilns? We have yet to see such heat in a kiln, but we know that several manufacturers claim to get such heats in the bottom of their kilns. The furnaces on such kilns are very deep and carry heavy beds of fuel. The combustion is carried on with less than the theoretical amount of air, for it is a practical fact that we can get higher temperatures with less than 100% of air than with an air excess, probably because we can keep nearer the 100% mark by erring on the lower side. During the finishing stages the furnaces are crowded to their utmost limit, thereby reducing the percent radiation loss to a minimum. In this way a kiln temperature approximating the theoretical flame temperature of the fuel can be obtained. Several years ago one manufacturer introduced in down draft kilns a method of preheating the air, together with forced draft and some water gas, but we do not know what the success of the method has been.

Forced draft should be a decided advantage in that it greatly increases the rate of fuel consumption and thereby lowers the percent radiation loss.

WHY DOES THE AMERICAN POTTER HAVE TO FIRE HIS EARTHENWARE THREE OR FOUR CONES HIGHER THAN THE ENGLISH POTTER?
A COMPARISON BETWEEN AMERICAN AND ENGLISH EARTHENWARE BODIES.

BY

KENDE ELEÖD, Trenton, N. J.

Every earthenware manufacturer in the United States will admit that English earthenware (C. C., P. G., Semi-Porcelain, Semi-Vitreous China, etc.) is, generally speaking, superior to that produced in this country. The Staffordshire Earthenware is of better texture, that is, it is more dense, or compact; the glaze, colors and the general finish of the English ware are superior. Sandy, rough edges are characteristic of American earthenware.

It is strange that English potters, operating in this country, could not reproduce same quality of crockery here, as is made in their home country, when having at hand the same materials,—the English china clay and English ball clay.

Earthenware	English	American
Biscuit	Cones 3—4—5	8—9
Glost	2—3	5—6

Why this additional heat for the American earthenware? And why, in spite of this heat, is it inferior in quality, less able to resist sudden changes of temperature

than the earthenware made in Staffordshire at a lower temperature?

There are at least two reasons. First, because the American earthenware body does not contain enough plastic clay, such as the English ball clay, which gives the English bodies their noted density. Secondly, in the American earthenware bodies the non-plastic materials are not ground fine enough.

It seems to me that most American potters do not realize the great necessity for English ball, or similar plastic clays, in an earthenware body. The great feature of the English ball clay is, as we know, that it vitrifies at a practically low temperature and remains so, without deformation by additional heat, for a long time. This is characteristic of the so-called "Stoneware clays." (Steinzeugton.)

One might say that the greatest pottery center in the world, the Staffordshire Pottery District, was built up on the quality of that famous plastic ball clay, without which I can not imagine the great industry in that district to have attained its present wonderful development. Without it, Josiah Wedgwood could never have produced his world famous Queen's Ware, Jasper, Basalt or Granite Wares.

Wedgwood made his Queen's Ware out of ball clay, china clay and Cornish stone. In his Cameos he used ball clay, china clay, Cornish stone and heavy spar. In both of these the ball clay always played a very important part in the body, giving plasticity in the making of those precisely modeled pieces and that typical vitreousness, characteristic of the stoneware clays, after being fired.

ENGLISH EARTHENWARE BODIES.

Very old earthenware bodies in Staffordshire were made without flint, as for example, the following recipe, which I found in a book from a Staffordshire Free Library.

16 inches Ball Clay,	24 oz. to the pint
11 inches China Clay,	26 oz. to the pint
11 inches Cornish Stone,	32 oz. to the pint

which figures out in dry weights to about

1×16 = 16.0 parts of dry Ball Clay	24.40%
1.5×11 = 16.5 parts of dry China Clay	25.20%
3×11 = 33.0 parts of dry Cornish Stone	50.40%
	100.00%

These old English earthenwares, (one might better call them "White Stoneware"), were the best of their kind ever produced, not for color, but for durability.

Later on, competition grew sharper and sharper and the public unwisely demanding a whiter body, the potters in Staffordshire were pressed to make up their bodies to meet that competition and requirement. They began to increase the flint content in their bodies, and at the present time the tendency is to use less ball clay and replace the stone with Norwegian spar.

E. A. Sandeman in his "Notes on the Manufacture of Earthenware," gives the following formulas for earthenwares:

	A good	B medium	C common
Ball Clay at 24 ozs. to the pint..	10 in.	11 in.	15 in.
China Clay at 26 ozs. to the pint..	8 in.	9 in.	8 in.
Flint at 32 ozs. to the pint..	5 in.	4½ in.	4 in.
Stone at 32 ozs. to the pint..	2½ in.	2½ in.	2 in.
Stain at 25 or 28 ozs. to the pint in varying proportions according to the color required.			

These figure out in percentage dry weights to about:

	A	B	C
Ball Clay	22.4	24.2	33.3
China Clay	27.0	29.6	26.7
Flint	33.7	29.6	26.7
Stone	17.0	16.5	13.3
	100.1%	99.9%	100.0%

The following are more modern Staffordshire earthen-

ware body formulas, showing "wet" inches and percentage dry weights:

	D—vitrified	E—common
Ball Clay at 24 oz. to pint.....	14 in. 18.5%	14 in. 18.5%
China Clay at 26 oz. to pint.....	13 in. 25.8%	13 in. 25.8%
Flint at 32 oz. to pint.....	6 in. 23.8%	8 in. 31.8%
Stone at 32 oz. to pint.....	8 in. 31.8%	6 in. 23.8%
Stain at 25 oz. to pint (in varying proportions)		
	99.9%	99.9%

	F Ivory	G	H	
Ball Clay at 24 oz. to pt...16 in.	27.0%	29.0%	28.5%	Ball C.
China Clay at 26 oz. to pt... 9 in.	22.6%	27.0%	27.5%	China C.
Flint at 32 oz. to pt... 7 in.	35.3%	28.4%	32.5%	Flint
Stone at 32 oz. to pt... 3 in.	15.1%	15.1%	10.5%	Feldspar
Stain at 25 oz. to pt...Rutile in varying proportions		99.5%	99.0%	

AMERICAN EARTHENWARE BODIES.

If you compare these English formulas with the American, first you will notice the high amount of ball clay in them.

I have figured out the dry weights, as I think nearly all the American potters mix their bodies up dry. There has been so much said in this country, in the past, about "wet" and "dry" mixing, and still without visible effect, that I do not intend to say much more about it here, only that I am a strong believer in "wet" mixing.

American earthenwares hold, as far as I know, but 8 to 12 percent of ball clay in them. As I am not in a position to disclose American formulas given to me in trust, I can only give approximate figures, which will serve for comparison with the English recipes.

	I	J	K	L
American Ball Clay	....	....	....	06.0
English Ball Clay	08.0	10.0	07.5	04.0
English China Clay	30.0	38.0	22.5	22.0
American China Clay, I	05.0	06.0	09.5	08.0
American China Clay, II	15.0	02.0	17.5	17.0
Flint	30.5	32.5	32.0	32.0
Spar	11.5	11.5	11.0	11.0
	100%	100%	100%	100%

There is 18.5 per cent to 35 per cent of ball clay in the English bodies, as compared to 8 to 10 per cent only in the American bodies of the East. I never saw an American earthenware in which I could trace much more ball clay than as stated above, although I have heard as much as 15 percent is used in the West.

The physical character of ball clay has to be considered seriously before we try to replace the clay substance, quartz and feldspar in ball clay with other clays. This, the American potters failed to do.

Conditions in continental Europe, in the earthenware line, are somewhat similar to those here. The manufacturers there are not using sufficient English ball clay or a sufficient quantity of a very similar stoneware clay. Their plastic white burning stoneware clay is not so good as the English ball, and consequently, their ware is inferior to the Staffordshire makes. It does not stand the sudden changes of temperature as well as the Staffordshire crockery, which gets its density, or vitrification, by virtue of the ball clay contained therein, while the continental potters rely on spar, stone, dolomite, etc., for their vitrification. Their ware may be just as vitreous, but it does not stand the knockings so well and is more liable to produce crazed ware, similar to the American.

Going back some sixty or eighty years we find that the English earthenware (Hartsteingut) had the reputation

of being the best crockery made. The Germans, especially, were very anxious to get the secret and to produce equally good ware in Germany. Very likely, they analyzed several of these wares and found out their chemical compositions, but they made a mistake in not considering the physical properties of the materials, especially that of ball clay. Apparently they neglected that part of it, and were satisfied with finding the amount of clay substance, quartz and feldspar content.

There are many clays with a similar chemical composition to English ball clay, but there are few, if any, whose physical properties are identically as good. The yearly import figures of that material will best prove my statement.

Most of the white "Sanitary" potters in this country would have to close down their plants temporarily could they not have ball clay from England, because their sanitary body is based on the quality of the English ball clay.

American potters, I am told, suffered terribly with crazed ware, and even now crazed pieces are not uncommonly seen. It is a very unusual thing to see crazed goods from Staffordshire. For some reason or other, American potters did not want to use much of the English ball clay, but replaced it with either American ball clay, which is not quite so plastic, or with American plastic kaolins. Such compositions, fired at a Staffordshire earthenware biscuit heat, cone 3 to 5, would not burn dense enough, besides which they did not succeed in finding a non-crazing glaze for it. At this period they must have suffered badly with crazing. Gradually they had to fire harder and harder to secure the required density, until in the biscuit kilns they had reached the temperature of cone 8 or 9.

There are more reasons than one for wishing to decrease the content of the English ball clay. It blunges up very hard; it has much organic matter and other impure residues, which choke the lawn and wear it out more quickly; it passes through the filter presses slowly,

needs more cobalt stain to counteract its yellowish tinge; and the danger of warping and firecracking is always present.

For a simple demonstration, take the English body H and the American body I:

In *H* we have 56 per cent of plastic materials

In *I* we have 58 per cent of plastic materials

with comparatively equal amount of non-plastic ingredient, 44 per cent in *H*, and 42 per cent in *I*. Mix the plastic materials in *H* together alone, without the non-plastic materials and fire at cone 3. Do the same with the plastic materials in *I*. The *H* fired trials will be nearly vitreous, while the *I* trials will be very porous. I am sorry that I did not have the time or facilities to mix up these trials and figure out their porosity, so as to give the illustrations in actual figures; but everyone who has handled English ball clay will readily admit that the *H* trials, with more than half ball clay in them, will be far denser, stone-hard, compared with the *I* trials, in which there is only 14 per cent of ball clay.

We know that with a fusible substance, such as feldspar or stone, we never get the quality of vitrification in earthenware body, nor even in a china body, that we can secure with a plastic clay.[1] American earthenware bodies, similar to those given here, lack plasticity to secure sufficient density, or natural vitrification, but are largely dependent on feldspar to bind together in a higher fire.

Now and then trouble springs up in an American plant owing to the ware coming from the glost kiln crazed, though everything seems to be going as usual. First, the biscuit warehouseman is blamed for letting through easy-fired ware, or the fireman for finishing his kiln too soon. Then the sliphouseman is questioned, when the fault really lies in the body itself not having a safe margin for practical manufacturing.

The second chief reason is, the non-plastic materials

[1] Reg. Rath Dr. H. Hecht.

in the American earthenware bodies are very poorly ground, which produces the rough edges on a plate, for instance, which, when gilded, shows that sandy edge typical of American dinner sets.

The English manufacturers grind their flint, spar or stone wet; the Americans grind theirs dry, and therein lies the difference. We know the great difference in the two ways of grinding, and many of you here present have surely tried to secure wet ground, or at least finer ground materials, without success. Why not get together and demand wet ground flint and spar? Not until then will the American potter be able to manufacture equally as good wares as the imported.

The flint and spar mill owners here seem to believe in a twelfth lawn as a guage for the fineness of their dry ground materials, thinking it sufficiently ground if it passed that lawn without too much residue. Gentlemen, we know what a big mistake that is. In Staffordshire they float their flint and spar, or stone. I know of one of the largest plants there, in Hanley, where, after the flint is fine ground they stop the mill, and then after about ten minutes settling, they use the top ten inches only, the very finest. The material is, at that stage, so finely ground that it does not grit between the teeth. Everybody to whom I have mentioned that fact knew of it and agreed with me, and yet nothing is done towards remedying it.

Generally speaking, the American decorated earthenware lacks those brilliant colors seen on English goods. The reason for this is the high heat at which they fire the glost kiln; and, for another reason, the unaccountable use of ZnO in their glaze. ZnO, as we know, turns the green colors derived from Cr_2O_3, a dirty, more or less brownish color, in the same way that it discolors the chrome-tin pinks and others.

Let it be understood that when I speak of American earthenware I do not include the so-called "American China," though some of that is nothing more than harder

fired vitreous earthenware. Two years ago, technically interested in making American china, I tried in one instance to convert our biscuit kiln, ordinarily downdraft, into a European porcelain, "Glattbrand," kiln, in which the atmospheric condition at a minute's notice, can be changed from oxidizing to reducing, by putting a large iron damper on top of the cone outside.

I have succeeded in "bleaching" our china biscuit, buried in flint, with the same method as the German china is fired in the "Glattbrand." I am confident that using the same body composition, but omitting the stain, which would produce a blue coloration, the American china now manufactured can be improved in color considerably from its slightly greyish-white, or slightly yellowish white, into a clear white color, which is so characteristic of the foreign porcelain. At one time I had a doubt that this white color would reoxidize again in the glost kiln, at least on the surface, but my experiments proved that it retained its color.

If we should take an English earthenware biscuit plate, for instance, glaze it and fire it in an American glost kiln, the result would be sandy edges, just as though it had been an American biscuit plate.

On the other hand, should we take an American biscuit plate to England, glaze it there and fire it in an English earthenware glost kiln, the result would be that the edges would be perfectly covered with the glaze, just as though the biscuit had been English instead of American.

The point I wish to make is that the difficulty about the sandy edge problem lies not alone in the make up of a body, but is also a question of heat and the nature of the glaze applied.

The English earthenware glaze maturing at three cones lower than the American, permits the use of a higher amoutn of lead and boracic acid, which two materials combined make a better and smoother glaze.

Recently I took a C. C. plate (biscuit) made in a Trenton pottery, and glazed it with a raw lead glaze

$$PbO \cdot 0.19\ Al_2O_3 \cdot 2.02\ SiO_2$$

63.63	White Lead
24.24	Flint
12.12	China Clay
99.99%	

and fired it to cone 5. The glazed plate came out with the edges nicely covered.

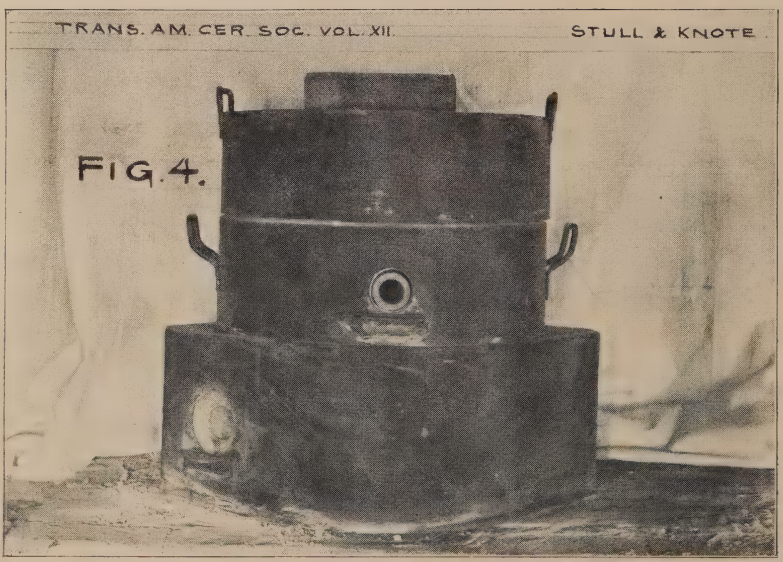
The conclusion to be drawn from the foregoing would seem to be that to overcome the sandy edges the heat in the glost kiln should be lowered from cone 5-6 to cone 2-3, which would be made possible by using a glaze with a higher amount of lead-boron in it and by discarding the ZnO altogether.

A NEW TYPE OF LABORATORY TEST KILN.

BY

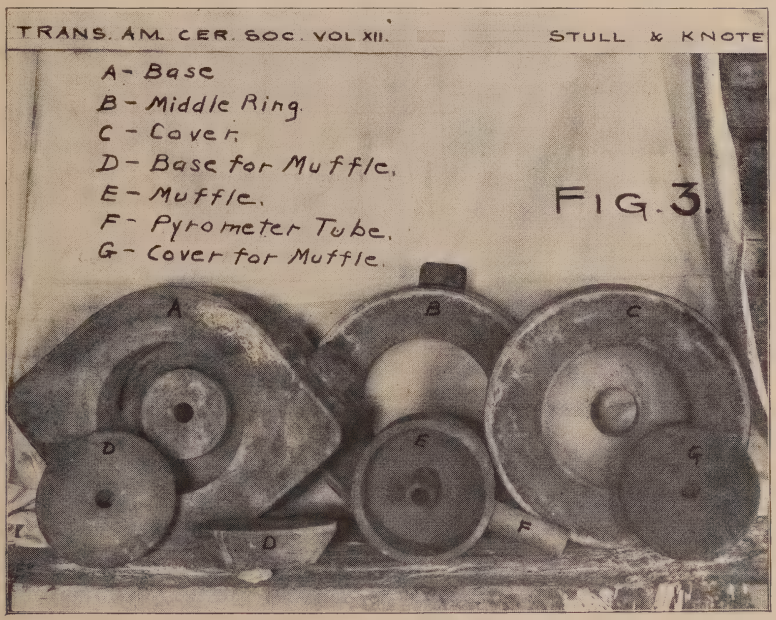
R. T. Stull and J. M. Knote, Urbana, Ill.

Some very ingenious kilns have been designed for conducting ceramic experiments, but the conditions which are to be met are so varied that it is difficult to secure one which is really satisfactory for a variety of purposes. The



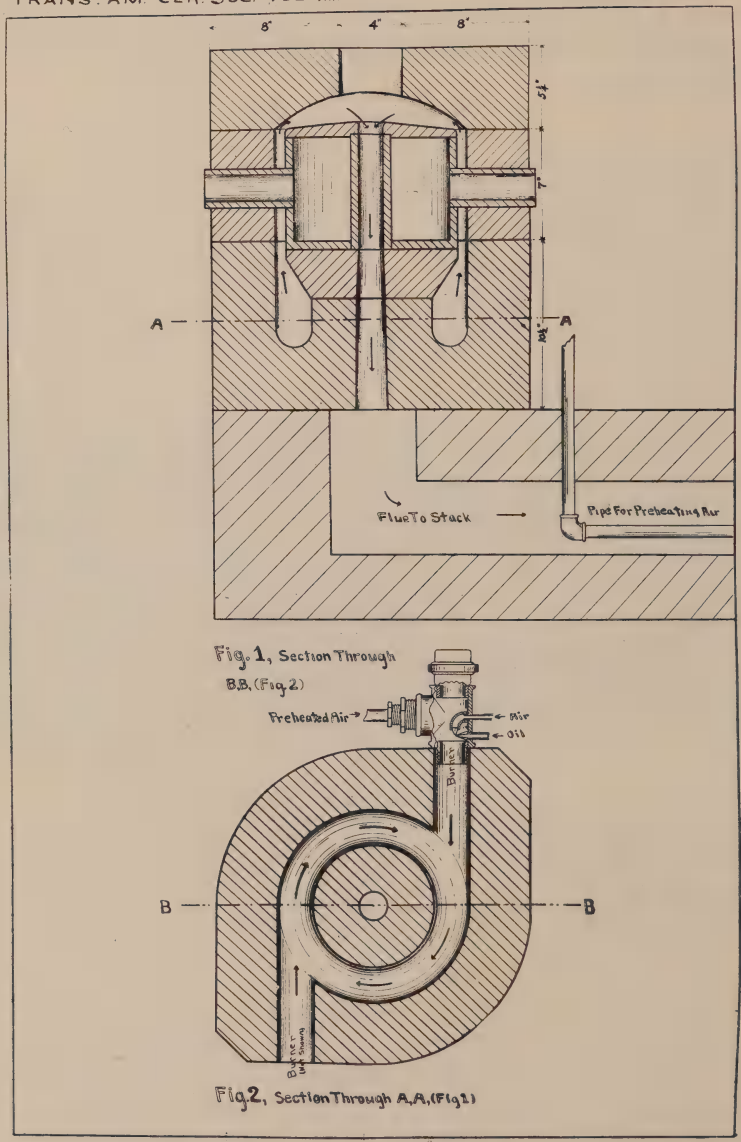
desirability of a convenient kiln is so great, that we thought ourselves justified in making an effort to construct what has proven to be a very satisfactory kiln for our work. It was designed to enable us to burn trials to any temperature we desired, as rapidly as we wished, and at the same time

be sure of securing a uniform distribution of heat throughout the ware chamber. The drawings and photographs illustrate the construction of the kiln which best meets our requirements.



METHOD OF CONSTRUCTING KILN.

Accurate full sized drawings were made of each part, and from these the necessary zinc templets were marked out, for the purpose of making a plaster of Paris model of each part after the method used in terra cotta work. From the models plaster moulds were made. All the parts of the furnace were pressed by hand in these moulds, except the clay tubes, which were run out on a small auger machine. For ordinary work all parts of the furnace were made of a mixture of refractory fire clays, containing 30% plastic fire clay and 70% calcined flint fire clay. For high


8"
4"
8"
5½"
7"
A
A
Flue To Stack
Pipe For Preheating Air
Fig. 1, Section Through
BB, (Fig 2)
Preheated Air
Air
Oil
Burner
B
B
Burner
Fig 2, Section Through A,A, (Fig 1)

temperature work, calcined bauxite bonded with a good plastic fire clay is better. All pieces were well burned before being used. The three pieces which make up the body of the furnace, were jacketed with 3-32″ iron, cement being used as a filler between the clay and the iron.

Burners. The furnace can be fired with either oil or gas. In Fig. No. I, the oil burner we used is shown. It was made entirely from stock fittings. The body of the burner is an inch and a half tee drilled and threaded for quarter inch pipes to admit the oil and high pressure air for spraying the oil. The hole through which oil is admitted was made by a 60-gauge drill. It is easier to get this hole too large than too small. To enable the operator to watch the burner, a union in which a piece of isinglass is placed, is screwed on to a short nipple in the back end of the tee. The burner works best with the oil under four or five pounds pressure and the air for atomizing at 15 pounds or more. The main air supply for combustion may be used at a pressure of a few ounces up to 80 pounds. When going to full capacity about fifty cubic feet of free air per minute must be supplied.

RESULTS.

As a means of distributing the heat uniformly, the revolving flame is a good thing, even when only one burner is used. It produces a continuous ring of burning gases around the muffle, and there is no chance for local heating if ordinary care is used in adjusting the burners. A patent was granted on the use of this principle in certain furnaces in 1905, but the senior writer adopted it as early as 1902, as a means of firing his fritt furnace at the plant of the American Terra Cotta and Ceramic Company, Terra Cotta, Ill. This furnace was secured by Prof. Purdy for the Ceramic Laboratory of the University of Illinois, and was extensively used in his experimental work on glazes and is still in successful use in this laboratory.

The down-draft passage through the center evens the

vertical distribution of heat and warms the center of the muffle. The advantage of using the waste gases to heat the air supplied for combustion is self evident, and has been done for a long time.

The kiln is used with the muffle in place for all temperatures up to cone 29, but for higher temperatures it is removed. Cone 33 has been reached readily, the firing being done with but one oil burner. It never has been necessary to use the second burner when oil is used for fuel, but we use two if the firing is done with gas.

The kiln was purposely designed to retard the escape of the combustion gases, somewhat, with the intention of forcing them to all parts of the kiln.

Several tests of the uniformity of the heat distribution have been made, and it is found that if the burners are adjusted properly practically no difference is to be noticed horizontally, but the bottom does get a little hotter than the top. This amounted to about a half a cone on a four-hour, cone 13 burn, and nearly a cone on a two-hour, cone 21 burn. But if more time is taken to reach the required temperature and it is then held for a time, better results can be obtained. We have burned a large variety of clays and glazes requiring temperatures from 550° C. up to cone 29, and have never found enough variation to affect our results. The cones can readily be watched through the peep holes, or if desired both cones and pyrometer may be used. If it is necessary to draw trials as the temperature advances, the lid of the muffle can be left off and the briquettes taken out through the hole in the furnace lid, by means of a pair of tongs.

The muffle, muffle lid and muffle base are liable to crack after being used some time, but this is not serious since they are so easily replaced.

OPALESCENCE AND THE FUNCTION OF B_2O_3 IN THE GLAZE.

BY

R. T. Stull and B. S. Radcliffe, Urbana, Ill.

In the study of whiteware glazes, at the University of Illinois, the class in glaze making constructed a group of glazes which showed all stages from clear colorless through opalescence to opaque white.

The group consisted of six series having nine members, each covering the following field:

$$\left.\begin{matrix}.3\ K_2O \\ .2\ Na_2O \\ .4\ CaO \\ .1\ PbO\end{matrix}\right\} .45\ Al_2O_3 \left\{\begin{matrix}2.1 \text{ to } 6.1\ SiO_2 \\ \\ 0 \text{ to } 1.0\ B_2O_3\end{matrix}\right.$$

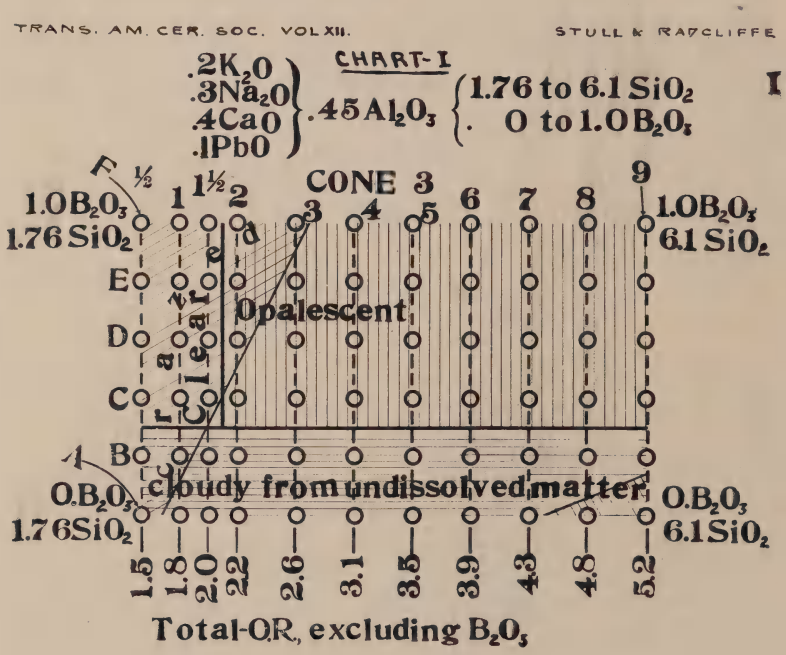
The glazes were applied to biscuit wall tile, set on edge in flat tile saggers and burned to cone 3. Examination of the trials seemed to indicate that opalescence was not a function of the quantity of boric oxide, since glazes having small molecular quantities appeared as opalescent or opaque as those having larger quantities.

There also seemed to be a dividing line between the clear and the opalescent glazes. Although the glazes had run and beaded along the edge of the tile, the thickness of the glazes against the white background of the tile was not sufficient to determine accurately the dividing line between the clear and the opalescent fields.

In order to determine more accurately this line, a series of glazes was inserted between what appeared to be the clear and opalescent fields, and another series added to the left of the group, thus covering the following limits:

$$\left.\begin{matrix}.3\ K_2O \\ .2\ Na_2O \\ .4\ CaO \\ .1\ PbO\end{matrix}\right\} .45\ Al_2O_3 \left\{\begin{matrix}1.76 \text{ to } 6.1\ SiO_2 \\ \\ 0 \text{ to } 1.0\ B_2O_3\end{matrix}\right.$$

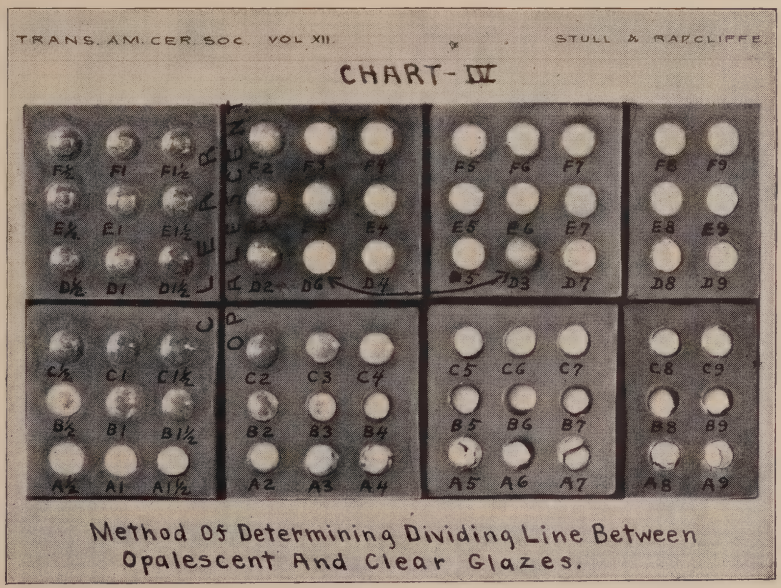
Each circle on the diagram (Chart I) represents a glaze. In the lower left hand corner is low boric oxide and low silica. In the lower right hand corner is low boric oxide and high silica. At the upper left corner is high boric oxide and low silica. In the upper right corner is high boric oxide and high silica.



In the series running horizontally from left to right, boric oxide is constant and silica increases, while in the series running vertically from bottom to top silica is constant and boric oxide increases.

In order to detect faint opalescence it is necessary to examine thick layers of the glazes. For this purpose tiles from stoneware clay were made having conical depressions one-half inch in diameter and one-fourth inch deep (Chart IV). These depressions were filled with the glazes, the wall tiles were dipped and the trials burned to cone 3.

Examination of the trials showed opalescence strongly in Series 2 running vertically. Glazes having low boric oxide seem to show as strong opalescence as those having higher quantities. The members in vertical Series 1½ do not show the slightest trace of opalescence. To the right of the dividing line, opalescence increases, while glazes in the field to the left are perfectly clear.


TRANS. AM. CER. SOC. VOL XII
STULL & RAFCLIFFE
CHART - III
F½ F1 F1½ F2 F3 F4 F5 F6 F7 F8 F9
E½ E1 E1½ E2 E3 E4 E5 E6 E7 E8 E9
D½ D1 D1½ D2 D3 D4 D5 D6 D7 D8 D9
C½ C1 C1½ C2 C3 C4 C5 C6 C7 C8 C9
B½ B1 B1½ B2 B3 B4 B5 B6 B7 B8 B9
A½ A1 A1½ A2 A3 A4 A5 A6 A7 A8 A9

Method of Determining Dividing Line Between Opalescent And Clear Glazes.

Some very interesting points with respect to crazing are observed. In the A series, A-½ is a basic matt and crazed. A-9, which is high in silica, is badly devitrified and crazed. A-8 is slightly devitrified and slightly crazed.

In the case of these two extremes of crazing the addition of boric oxide has had diametrically opposite effects. Boric oxide added to A-½ has increased crazing, the crazing increasing with increase in boric oxide. In A-8 and 9 the addition of boric oxide has overcome crazing and also devitrification.

In his article[1] on "The Function of Boron in the Glaze Formula," Professor Binns says: "It was noticed that from its position in the periodic curve and from its valence, boron might be presumed to act like alumina, functioning as a base with strong acids and as an acid with strong bases."

He also points out, that in a glaze having the formula RO, .2 Al_2O_3, 1.6 SiO_2, whose oxygen ratio is one to two, if .3 B_2O_3 be added it is necessary to raise the silica to two and one-half according to practice, and that if B_2O_3 be considered as base the oxygen ratio then becomes one to two.

Professor Binns further states: " * * *, the opinion is further expressed that B_2O_3 undoubtedly is basic when melted with silica or silicates, and that it may be used to replace alumina partially or entirely, with the exception of its exercise of the property of fusibility."

Dr. Zimmer says:[2] "While I admit that all the facts brougth out seem to indicate that boron will act as a base. there are surely conditions under which it will act as an acid."

If we arrange the oxides of the elements in groups according to the periodic system, we find, as a rule, that the bases of low molecular weight produce best opacity and bases of high molecular weight least opacity. With respect to acids, we find the opposite, i. e., acids of high molecular weight produce best opacity and acids of low molecular weight least opacity.

According to Seger's rules for crazing, bases of low molecular weight produce least crazing and bases of high molecular weight produce most crazing. Whether the opposite is true of acids has not been definitely shown.

By calculating the oxygen ratios of the glazes including boric oxide, lines of equal oxygen ratios are obtained running vertically across the diagram, as shown in Chart I.

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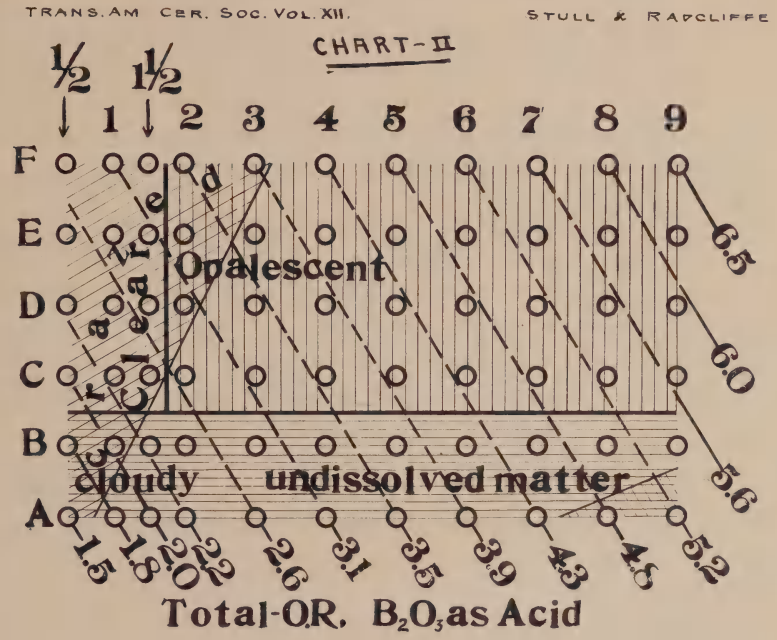
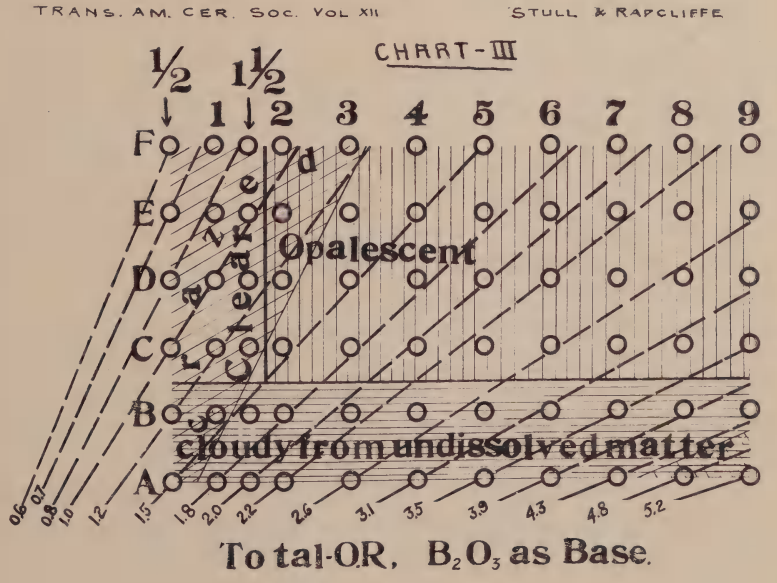
[1] Vol. X, Trans. A. C. S., p. 159.

[2] Ibid, p. 168.


TRANS. AM CER. SOC. VOL. XII.
STULL & RAPCLIFFE
CHART-II
½ 1½
1 2 3 4 5 6 7 8 9
F
E
D
C
B
A
Clear
Opalescent
cloudy undissolved matter
6.5
6.0
5.6
1.5 1.8 2.0 2.2 2.6 3.1 3.5 3.9 4.3 4.5 5.2
Total-OR. B_2O_3 as Acid


TRANS. AM. CER. SOC. VOL XII
STULL & RAPCLIFFE
CHART-III
½ 1½
1 2 3 4 5 6 7 8 9
F
E
D
C
B
A
Clear
Opalescent
cloudy from undissolved matter
0.6 0.7 0.8 1.0 1.2 1.5 1.8 2.0 2.2 2.6 3.1 3.5 3.9 4.3 4.8 5.2
Total-OR. B_2O_3 as Base.

Considering boric oxide as an acid, lines of equal oxygen ratios run diagonally downward from left to right (Chart II). Calculating oxygen ratios in which boric oxide is assumed to be a base, gives diagonal lines running upward from left to right which appear to radiate from a common center, (Chart III).

In Chart I it is observed that the dividing line between the clear and opalescent glazes runs parallel to and between the oxygen ratio lines of 1 to 2 and 1 to 2.2. Since opalescence is shown so strongly on the total oxygen ratio line of 1 to 2.2, it is reasonable to suppose that the true dividing line between clear and opalescent glazes lies on or very near to the total oxygen ratio line of 1 to 2.

In consulting Charts II and III, it is evident that the lines of equal oxygen ratios in which boric oxide is calculated either as an acid or a base, do not bear any definite relation to the dividing line between the clear and opalescent glazes.

Boric oxide fuses at a low temperature, forming a thin water-like fluid. In this condition it is one of the strongest igneous solvents at our command, and there are few inorganic oxides that it is not capable of dissolving. Silica added to it is dissolved and evidently combined, since silica is strongly acid in character in igneous fusion, the combination is probably some silicate of boron which produces a milky precipitate.

Opalescence in glasses containing boric oxide is not caused by crystallization, nor by that peculiar form of segregation which sometimes precedes it. If it were, then sudden cooling would leave the mass in an amorphous condition, thus giving a clear glass. A fusion of silica and boric oxide when suddenly cooled will show strong milkiness. Fritts containing boric oxide frequently show opalescence though cooled suddenly by quenching in water.

It is trus that a glaze cooled slowly will show stronger opalescence than the same glaze cooled quickly, but it must be remembered that precipitates require time to form. As

an example, the complete precipitation of magnesia by sodium ammonium phosphate requires several hours.

CONSIDERATIONS ON CRAZING.

Boric oxide when added to A-½ (which is basic in character), undoubtedly plays the part of an acid. Increasing boric acid has increased crazing. The more boric acid present, the greater is the degree of crazing.

In the case of A-8 and 9, which are highly acid in character, it is more than probable that the addition of boric oxide has combined as a base, and in so doing has overcome both devitrification and crazing.

In comparing the dividing line between crazing and non-crazing glazes, with lines of total oxygen ratios on the three different charts, we find that this line does not conform to any oxygen ratio lines, whether boric oxide be excluded from the calculations, or included either as acid or as base.

It has been noted that crazing has increased with increase in boric oxide in glazes whose previous total oxygen ratios are low. It has also been stated that this crazing is due to the presence of boric oxide as an acid, and as such, whether free or combined, its tendency is to reduce crazing. If boric oxide combines as a base, its influence should be that of overcoming crazing, since it is a base of low molecular weight (in accordance with Seger's rule).

If boric oxide when combined as a base acts like alumina and can replace alumina, then, any increase in boric oxide would decrease crazing the same as alumina, in accordance with the statement of Purdy and Fox.[1]

Boric oxide present as acid and boric oxide present as base influence crazing in opposite directions, which might be expected since the properties of bases and acids are opposite in character. In glazes which craze from excess boric acid, an addition of silica has a double influence in

[1] Fritted Glazes, Trans. A. C. S., Vol. IX, p. 178.

preventing crazing. By converting boric acid to boric base it decreases crazing acid and increases non-crazing base.

The reason that the line between crazing and non-crazing glazes does not conform to any oxygen ratio lines is because both free crazing boric acid and combined non-crazing boric base may both be present, and it takes a definite amount of the one to overcome the influence of the other. With reference to the dividing line between devitrified and crazed glazes and non-devitrified and non-crazed glazes, Chart III shows that the line coincides in direction with the oxygen ratio lines when boric oxide is considered as a base. But when referred to Charts I and II, it is shown that the line does not conform to the oxygen ratio lines in either of these two cases.

Although there are no absolute chemical proofs at hand, the following theories are advanced from the foregoing evidence:

First, boric oxide when added to a glaze whose previous oxygen ratio is less than 1 to 2 is present as an acid, combined, tending to produce a chemical equilibrium. Any excess is present in acid, uncombined, in solid solution. When present in the acid form its influence is that of producing clear glazes and crazing.

Second, boric oxide when introduced into a glaze whose previous oxygen ratio is 1 to 2, is present as an uncombined acid in solid solution, imparting clear and crazing tendencies to glazes.

Third, boric oxide when introduced into a glaze with a previous total oxygen ratio greater than 1 to 2 tends to produce chemical equilibrium by combining as a base, thus producing opalescence and non-crazing tendencies. Any excess boric oxide is present as an uncombined acid in solid solution.

Fourth, opalescence is caused by the precipitation of a silicate in which boric oxide is evidently basic. The intensity of opalescence does not depend upon the quantity of boric oxide present but upon the quantity combined as a silicate.

It is interesting to note that, although the line dividing crazing and non-crazing glazes does not conform to any oxygen ratio lines, it conforms nearest to the lines of equal oxygen ratio when boric oxide is assumed to be base. The oxygen ratio line of 1 to 2, when boric oxide is considered a base, passes through the middle of the field of best glazes found in this group.

DISCUSSION.

Mr. Parmelee: I have this suggestion that I wish some of those interested in the matter of opalescence would determine whether that is opalescence or fluorescence. Opalescence, as I understand it, is due or at least commonly attributed to internal fractures, while fluorescence is a different thing. It would be a comparatively simple thing to take a sample of glaze showing this description of opalescence and determine which it is. I think it would be a matter of some interest.

Mr. Stull: The trials just came out of the kiln a little while before the convention. The intention was to have thin sections made of them and examine them microscopically. We used the term opalescence because that is the term most generally understood, and because it appears like opalescence,—it has the color. We know that some precipitates are opalescent in appearance. The precipitates of aluminum hydroxide and silicic acid are suggestively opalescent. Richards, in his work on the determination of the atomic weight of silver, produced strong opalescence in the silver chloride which passed through the filter. The presence of minute solid particles in suspension may give the reflection of light nearly as well as cracks or flaws will do.

Mr. Shaw: I have had some experience with borax but I do not believe I can add anything. I have been wondering what is the relation between opalescence and opacity. Substances that produce opacity if fused hard enough will produce opalescence. I have produced white enamel

and very often had it "burned." The opacity is all burned out of it, and the glaze after that time very often shows a great amount of opalescence.

Mr. Binns: Would you define opalescence as a partial opacity?

Mr. Shaw: That is exactly what I think.

Mr. Stull: I agree with that, that opalescence is a "dilute" state of opacity. Here is F9, (exhibits trial), the one highest in B_2O_3, and highest in silica. It shows opaque white.

Mr. Binns: I would like to ask Mr. Stull whether he has any explanation of the connection between devitrification and crazing. We have generally considered the two things were influenced by opposite conditions. I would be interested to know what suggestions he has to make on that point.

Mr. Stull: Most generally crazing is conceded to be a function of the co-efficient of expansion and contraction, but personally I think there is another factor which we do not consider, and that is crystalline tension. We know that crystals form from gases, from fluids and from solids. As a time-worn illustration, the iron beams of railroad bridges frequently become so crystalline from the jar of the trains that they become weak and break. We have plenty of evidence of crystallization going on in solids. A substance in crystallizing usually does one of two things, it either increases in volume or decreases in volume. In either case if crystallization should continue down into the solid glaze it would produce a tension strong enough to cause crazing. In experimenting with crystalline glazes of the type which crystallize in assicular groupings, I have failed to make one crystalline glaze yet which did not craze. In these crystals which radiate from centers, it is interesting to note that the craze marks did not run in irregular zigzag lines, but ran approximately in broken concentric rings around the crystalline center in this manner. (Indicating on the board as shown herewith.) If it

is not due to crystalline tensions, then what is it due to? Crystalline glazes with oxygen ratios all the way from one to one up to one to five will craze if they are crystallized. In practice I tried to overcome it by slow cooling from vanishing red heat down. The slower the cooling the worse the crazing appeared.

Assicular Grouping Showing Craze Marks Running Concentrically.

Mr. Binns: I would like in that connection to make another suggestion. We commonly theorize or philosophize this way: Silica in a body, being crystalline, has a high co-efficient. In the case of excess of silica in the glaze and consequent devitrification, it seems to me quite possible that the silica has returned to its crystalline form, and thus regained its high co-efficient. I have no doubt that Mr. Stull's theory of crystalline tension strains has something to do with it. At the same time I think the fact that the silica has returned to its crystalline form is also an important factor. I have frequently noted in that connection that a short fired glaze almost invariably crazes simply because the silica has not been thoroughly taken into the solution, and has thus not reached the amorphous form with the low co-efficient.

And now the question of boron, in which I am naturally very much interested. I would like to say just a word on that. This is the first time it has been alluded to since I brought it up two years ago. It is quite gratifying to find that at least a portion of my contention is substantiated. Dr. Singer showed, in his paper, that it was possible to produce compounds in which boron sesquioxide, or boric oxide, functions as a base.

Ever since the paper was presented two years ago I have worked upon the theory, which I then enunciated, that in a normal glaze under normal conditions boric oxide functions as alumina. And my students in the blackboard work have said to me, why do you put boric oxide under the alumina when all the books do the other thing and put it under the silica? I tell them if they live long enough they will find that all the books will have it under alumina.

Mr. Stull has brought up certain exceptional conditions, as for instance, in a highly basic glaze, where it is quite probable that a portion of the boric acid or all of it may function acidically. And by the way, I wish we had some better term than acid and base to express this action.

For many years I groped in the dark with regard to fritted glazes, and I believe a good many are doing so still. But when we once established that the bi-silicate ratio was the best thing for a clear glaze under proper conditions, there did not seem to be any philosophy or working reason why fritted glazes should not come under the same rule, in other words, why boric oxide should introduce an entirely new set of laws. But by the simple arrangement of placing boric oxide with the sesquioxides the whole thing is solved. Fritted glazes now obey the same law. They are normally bi-silicate, or closely approximating it. I have no more difficulty now in laying down fritted glazes than I used to have in raw glazes. But until this point was reached there was no law which could be used as a guide.

We are very glad to have this word from Mr. Stull not only on the boric question, but on that rather obscure and interesting phenomenon of opalescence which has occupied us today. He has also demonstrated his work in a very interesting manner. His enclosing the panel of glaze in the cell is quite a new idea and one well worthy of consideration, when we come to deal with the consistency of the glaze matter.

THE RELATION BETWEEN THE TENSILE STRENGTH AND TRANSVERSE STRENGTH OF RAW CLAYS.

BY

H. RIES AND S. W. ALLEN, Ithaca, N. Y.

It has often been customary in the past when testing raw clays, to make a determination of the tensile strength of the air-dried material, it being thought by many that this gave a clue to the clay's ability to stand strains in handling before burning, and possibly also to its bonding power.

But while the tensile strength test is still used by many persons, it was not recommended by the Ceramic Society's Committee for Co-operation with Federal and State Geological Surveys.[1]

The suggestion was recently made to the senior author of this paper, that it would be of more practical value to make a test of the transverse strength of the air dried clay instead of its tensile strength, as such a test would approximate more closely the conditions to which many pieces of clay ware (especially large ones) were subjected, before burning. It was thought that a transverse test would involve more difficulty and chance for error, because of the anticipated trouble of getting a piece free from irregularities of form; that unless the bar to be subjected to a transverse test was perfectly straight, the results might be unreliable. If, however, the transverse strength of air dried clay stood in direct relation to the tensile strength, and this seemed a logical inference, then the tensile strength test might still be used.

[1] Amer. Cer. Soc. Trans., Vol. IX, p. 741, 1907.

The following tests were undertaken with a view towards determining, (1) whether the transverse strength was directly proportional to the tensile strength, and (2) whether the transverse test was a difficult one to make. The laboratory work was all performed by the junior author.

The tensile strength test was made in the usual manner, by molding the thoroughly kneaded clay into briquets and pulling them apart in a cement testing machine.

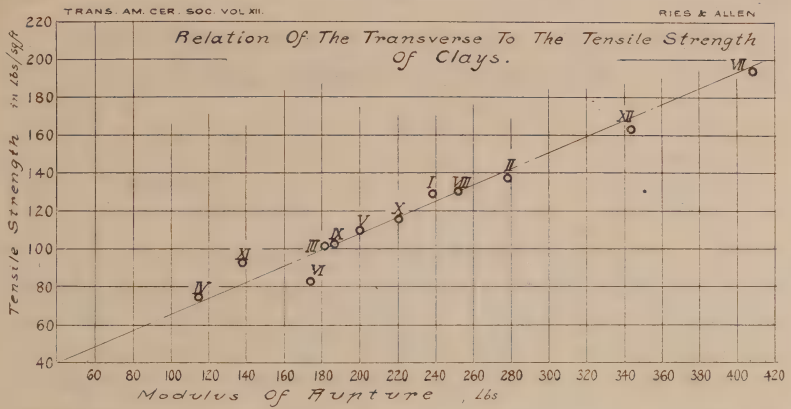
For the transverse test, the clay was carefully molded into bars 3½ inches long, and having a cross section of about 1.25 by .70 inches when dried. The surface of these was rubbed smooth and flat with sandpaper.

These bars were supported on rounded wooden edges, 2½ inches apart. A steel rod 3-16 in diameter, was laid across the bar of clay exactly half way between the supports, and from this a pail was suspended. Shot was fed into this pail until the bar broke.

The break in every case was smooth, and the results showed less variation than those obtained in breaking the briquettes. In each case twelve pieces were tested.

The clays or mixtures tested were the following:

I. Kentucky ball clay 75%, flint sand, ground to pass through 200 mesh, 25%.
II. Kentucky ball clay 50%, flints and 50%.
III. Florida ball clay 75%, flint sand 25%.
IV. Florida ball clay.
V. Kentucky ball clay.
VI. New Jersey fire clay.
VII. Red shale clay, Woodbern, Nova Scotia.
VIII. Red shale clay (No. VI) 75%, flint sand 25%.
IX. Red shale clay (No. VII) 50%, flint sand 50%.
X. Terra cotta mixture from New Jersey.
XI. Bath-tub mixture, obtained from factory.
XII. Black clay from New Jersey, used in manufacture of terra cotta.



In the accompanying chart the ordinates represent the modulus of rupture figured from the transverse test, while the abscissas represent the tensile strength of the air dried clay in pounds per square inch.

Each plotted point therefore represents the intersection of the lines corresponding to the modulus of rupture and tensile strength. The samples were arranged according to ascending modulus rupture, and from this it will be seen that a remarkably regular curve is obtained, the tensile strength rising directly with the transverse strength. No. VI appears to show the greatest divergence, and this was probably due to some flaws in the test pieces.

Considering the details of manipulation, the writers believe that the transverse test is as easy to make as the tensile strength test, and gives more uniform results.

Two points of interest may be further noted:

No. VII, in red shale, had an average tensile strength of 194 pounds per square inch. The addition of 25 per cent flint sand lowered the strength to 130 pounds per square inch, while with 50% fine sand added the tensile strength was only 102 pounds per square inch.

The Florida ball clay, IV, showed 74 pounds tensile strength, but the addition of 25% fine sand raised it to 102 pounsd per square inch. The same held true of Nos. V, I and II.

METHODS OF ANALYSIS FOR ENAMEL AND ENAMEL RAW MATERIALS.

BY

ROBERT D. LANDRUM,[1] Lawrence, Kansas.

Introduction. The fact that practically nothing has been published on the above subject, and the remembrance of the many long hours spent in digging out these methods and adapting them to enamels and enamel raw materials, has led the author to put them in this form for others who might use them. While he claims little originality in the methods themselves, he does claim originality in the adaptations here given. Each and every one of these methods has been thoroughly tried out, either in the laboratory of the Columbian Enameling and Stamping Company, at Terre Haute, Ind., or in the chemical laboratories of the University of Kansas.

PART I.

THE ANALYSIS OF AN ENAMEL.

The analysis of an enamel presents one of the most difficult and complicated problems with which the analyst comes in contact. An enamel is generally an insoluble silicate containing besides silica, iron, alumina, calcium, magnesium and the alkalies, generally boron, fluorine,

[1] This paper was prepared as a thesis for the master's degree at Rose Polytechnic Institute. The author desires to render thanks to Dr. W. A. Noyes and Dr. John White, his former instructors, for advice freely given, and to Dr. E. H. S. Bailey and Dr. H. P. Cady for suggestions offered. Methods, especially from the following sources, have been freely used, and adapted to the specific uses herein described: Treadwell and Hall's "Analytical Chemistry"; Classen's "Ausgewahlte Methoden der Analytischen Chemie"; Sutton's "Volumetric Analysis"; Lunge and Keane's "Technical Methods of Chemical Analysis"; "Methods of Agricultural Analysis" (Bul. 107, U. S. Dep't of Agric.); Hillebrand's "Analysis of Silicate Rocks" (U. S. Geol. Survey Bul. 305); and the files of the Journals of the various Chemical Societies.

manganese, cobalt, antimony and tin, and sometimes phosphorus and lead. Before attempting the quantitative analysis of any enamel a thorough qualitative analysis should be run, and this will enable one to choose a quantitative separation. One of the most important aids to a correct analysis is a thorough grinding. The sample should be ground to an almost impalpable powder, and every conceivable precaution for accuracy taken.

The analysis of a sample of enamel to be taken from a piece of ware involves an extra difficulty. The coating of enamel almost always consists of two or more layers—the lower a large ground coat, and the upper ones white or colored enamels. For an illuminating analysis these must be separated. The author has found the following method of V. de Luyeres[1] good for doing this: The surface is scratched lightly with a piece of emery cloth or a file, and a coating of gum acacia or glue is applied. The vessel is placed in an air-bath and heated. The glue on hardening generally carries with it some of the outer coat. The glue or gum is then broken off, dissolved in water and the enamel pieces collected on a filter paper. Some obstinate enamels require painstaking methods, such as chipping off with a chisel and separating the different coats—which always vary somewhat in color—by picking out and sorting, using a pair of forceps. A large reading glass will be useful in making these separations. Any iron from the vessel which may adhere to the enamel may be removed by means of a magnet after the sample is ground.

Analysis of an Enamel Containing Fluorine.

In an enamel containing fluorine the usual methods for silicates cannot be used, as silicon-tetra-fluoride would be volatilized in the evaporation with hydrochloric acid for the separation of the silica.

Fluorine. One gram sample is very finely ground, slowly fused with two grams each of potassium carbonate

[1] Compte Rendus 8, p. 480.

and sodium carbonate. The melt should be kept in quiet fusion over as low a flame as possible for one hour. The melt is transferred, (after cooling quickly by giving the crucible a gyratory motion while held in the tongs, causing the melt to cling to the sides instead of forming a solid cake in the bottom), to a platinum dish where it is covered with a watch glass and boiled vigorously with one hundred cc. of water. The residue is filtered off and is saved for the determination of the metallic oxides and the silica.

The covered solution is digested on a steam bath for an hour with several grams of ammonium carbonate, and on cooling more carbonate is added and the solution is allowed to stand for twelve hours. The precipitate of silica, alumina, etc., is filtered off, washed with ammonium carbonate water and is saved for further determinations.

The solution containing all the fluorine and traces of silica, phosphate, etc., is evaporated until gummy, then diluted with water and neutralized as follows: Phenolphthalein is added, and nitric acid (double normal) drop by drop until solution is colorless.

The solution is boiled and the red color which reappears is again discharged with nitric acid, boiled again and neutralized again until one cc. of acid will discharge the color.

The last traces of silica, etc., are now removed, as recommended by F. Seemann (Zeit. Anal. Chem. 44, p. 343), by the addition of 20 cc. of Schaffgotsch solution. This solution is made as follows: 250 grams of ammonium carbonate are dissolved in 180 cc. of ammonia (0.92 sp. gr.) and the solution is made up to one liter. To the cold solution 20 grams of freshly precipitated mercuric oxide are added and the solution is vigorously shaken until the mercuric oxide is dissolved.

The precipitate caused by the Schaffgotsch solution is filtered off and saved, and the solution is evaporated to dryness and the residue taken up with water.

Any phosphorus from the bone ash used in some enam-

els, and chromium which may be present, are removed from this alkaline solution by adding silver nitrate in excess. Phosphate, chromate and carbonate of silver are here thrown down and may be determined if desired.

The excess of silver is removed from the solution by sodium chloride, and one cc. double normal sodium carbonate solution is added to the filtrate, and the fluorine is precipitated by boiling with a large excess of calcium-chloride solution.

The precipitate, consisting of a mixture of calcium carbonate and fluoride, is collected on a blue ribbon filter paper and is washed, dried, ignited at low red heat, separated from the filter paper, and the residue with the ash of the paper is treated with dilute acetic acid until carbon dioxide is no longer given off on heating. The liquid is then evaporated to dryness, the residue taken up with hot water (slightly acidified with acetic acid) filtered, dried and gently ignited and weighed as CaF_2. This may be checked by heating with sulfuric acid, driving off all the excess of acid and reweighing as $CaSO_4$. This method gives results for the amount of fluorine checking within 0.2%, but which are generally from 2% to 4% low.

Silica. For the estimation of silica and the metallic oxides, first the precipitate from the Schaffgotsch mercuric oxide solution is ignited to drive off the mercuric oxide, and the silica left is weighed. The residue from the original melt, together with the precipitate obtained by ammonium carbonate (after the drying and removal from the filter paper whose ash is added) are then dissolved in hydrochloric acid. The solution is evaporated to dryness and moistened with hydrochloric acid. It is diluted with water and the silica is filtered off, weighed, and this with that previously obtained is the total silica.

Iron, Alumina and Manganese. The solution from the silica is raised to boiling and the iron and aluminum are precipitated as hydroxides. Then 5 cc. of bromine water is added and the boiling continued for five minutes.

The precipitate is dried on filter paper and ignited separately from it in a weighed platinum crucible, to which the ash of the filter-paper is afterwards added. The precipitate consists of Al_2O_3, Fe_2O_3, and Mn_2O_3, and is weighed as such. It is then fused with fifteen times its weight of potassium pyrosulfate over a low flame for three hours with the crucible covered. The crucible, contents and cover are placed in a beaker and dilute sulfuric acid (10:1) is added. By warming and continued shaking of liquid complete solution may be obtained. It is then drawn through a Jones Reductor to change all the iron to ferrous and titrated with N/10 potassium permanganate solution. The iron is calculated to Fe_2O_3 and the alumina determined by difference.

If manganese is present it is determined in a separate sample in a method given later and is subtracted from the iron in the above. In white enamels containing only a trace of iron the manganese may be determined in the solution from the pyrosulfate fusion. A freshly prepared solution of potassium ferricyanide is added to oxidize the manganese, then the solution is made alkaline with sodium hydroxide solution and the manganese-dioxide thus formed is filtered off. The solution is then made acid and the ferrocyanide is titrated with N/10 potassium permanganate solution. (1 cc. $KMnO_4 = 0.00435$ gram MnO.)

Calcium Oxide. The filtrate from the iron and alumina is raised to boiling, treated with boiling ammonium oxalate solution and digested on water bath until precipitate readily and quickly settles after being stirred. The calcium oxalate is now filtered off and ignited wet in platinum to constant weight over a strong blast.

Magnesium Oxide. The solution is evaporated to dryness and the residue ignited to remove ammonium salts. The residue is treated with a few drops of hydrochloric acid and taken up with boiling water and filtered from the carbonaceous residue. To the boiling solution is added drop by drop a solution of sodium ammonium phosphate

and is allowed to cool. Half as much concentrated ammonium hydroxide is added as there is solution and it is allowed to stand over night. The precipitate is collected on a filter, washed with 3% ammonia water, dried in oven and ignited separate from the filter. The heat is applied gently at first and finally with the highest heat of a good Bunsen burner. It is then weighed as $Mg_2P_2O_7$.

1 gram $Mg_2P_2O_7 = .3625$ grams MgO.

The alkalies are determined by the method of J. Lawrence Smith from a gram sample finely powdered. This method is standard and need not be given here.

Separation and Determination of Antimony, Tin. Manganese and Cobalt in Enamel.

Decomposition. Two grams finely powdered sample are transferred to a platinum dish, and after moistening with a little water, pure hydrofluoric acid is added and the whole is mixed with a platinum spatula. The dish is digested on steam bath for five hours covered with platinum cover (a larger platinum dish may be used for cover if no other is at hand). After the decomposition is complete the solution is evaporated to dryness on steam bath. The residue is moistened with enough dilute sulfuric acid (1 : 1) to make a thin paste, and evaporated as far as possible on a steam bath and then on a hot plate, all the time being covered to prevent spirting. As soon as fumes of sulfuric anhydride cease to be evolved the cover is strongly heated until fumes cease to be driven off, when it is removed. The contents are heated by bringing the dish to dull redness directly over a Bunsen burner. The sulfates thus formed are moistened with strong hydrochloric acid, a little hot water is added and the solution boiled with repeated additions of acid and water until completely in solution. In some enamels—especially those with high melting points—the stannic oxide remains un-

dissolved, and a fusion of the residue with sulfur and sodium carbonate as given later under "The Analysis of Oxide of Tin" may be necessary.

Treatment with H_2S. The solution containing at least 30 cc. double normal hydrochloric acid is transferred to a 500 cc. Ehrlenmeyer flask fitted with a double bored stopper. Through one of the holes a right-angled piece of glass tubing is introduced that just reaches to the lower edge of the stopper, while through another hole another right-angled glass tube is fixed so that it almost reaches the bottom of the flask.

A Kipp H_2S generator is connected to the longer tube and H_2S is passed through for half an hour and the solution is let stand for another half an hour, after which the sulfides of antimony and tin are transferred to a filter paper and the solution is kept for the determination of manganese and cobalt.

Antimony and Tin. The precipitated sulfides are dissolved in a solution of potassium polysulfide—if any lead or copper is present it will remain undissolved and may be determined separately—by pouring this successively through the filter into a 300 cc. Jena beaker, and finally washing with water containing a small amount of potassium polysulfide.

Antimony. The antimony and tin in this solution are separated by F. W. Clark's method as modified by F. Henz[1], as follows:

To the solution in the Jena beaker 6 grams caustic potash and 3 grams tartaric acid are added. To this mixture twice as much 30 per cent. hydrogen peroxide is added as is necessary to completely decolorize the solution, and the latter is now heated to boiling and kept there until the evolution of oxygen is over, in order to oxidize the thiosulphate formed. All of the excess of peroxide cannot be removed successfully at this point. The solution is cooled somewhat, the beaker covered with a watch-glass,

[1] Treadwell, Vol. II, p. 188.

and a hot solution of 15 grams pure recrystallized oxalic acid is cautiously added (5 gms. for 0.1 gm. of the mixed metals). This causes the evolution of considerable carbon dioxide. Now, in order to completely remove the excess of hydrogen peroxide the solution is boiled vigorously for ten minutes. The volume of the liquid should amount to from 80 to 100 cc. After this a rapid stream of hydrogen sulfide is conducted into the boiling solution, and for some time there will be no precipitation, but only a white turbidity formed. At the end of five or ten minutes the solution becomes orange colored and the antimony begins to precipitate, and from this point the time is taken. At the end of fifteen minutes the solution is diluted with hot water to a volume of 250 cc., at the end of another fifteen minutes the flame is removed, and ten minutes later the current of hydrogen sulfide is stopped. The precipitated antimony pentasulfide is filtered off through a Gooch crucible which, before weighing and after drying, has been heated in a stream of carbon dioxide at 300°C. for at least one hour. The precipitate is washed twice by decantation with 1 per cent. oxalic acid and twice with very dilute acetic acid before bringing it in the crucible. Both of these wash liquids should be boiling hot and saturated with hydrogen sulfide.

The crucible is heated in a current of carbon dioxide (free from air) to constant weight, and its contents weighed as Sb_2S_3.

The filtrate is evaporated to a volume of about 225 cc., transferred to a weighed unpolished platinum dish, and electrolyzed at 60° to 80°C. with a current of 0.2 to 0.3 ampere (corresponding to 2 to 3 volts). For very small amounts of tin, a current of not over 0.2 ampere should be used. At the end of six hours 8 cc. of sulfuric acid (1 : 1) are added, and at the end of twenty-four hours the solution is transferred to another dish. The deposited tin has a beautiful appearance, similar to silver.

Tin. The plated tin is washed thoroughly with water and the dish is dried in an air oven at 110° and weighed.

The solution containing the cobalt and manganese is boiled until free from H_2S. The iron is oxidized back to the ferric state by the addition of bromine water and boiling until the excess of the latter is expelled. Ten cc. double normal ammonium chloride is added and the iron and alumina are precipitated by the addition of ammonia and are filtered off. (The iron alumina may be determined from this precipitate if desired.)

The solution still containing the manganese and cobalt is transferred to an Ehrlenmeyer flask fitted for passing in H_2S, as before described, and 3 cc. strong ammonia is added. H_2S is passed through for some time, and after precipitation ceases 3 cc. more of ammonia are added and the flask is filled to the neck (300 cc. flask), is corked and set aside for twelve hours at least. The precipitate is collected and washed on a small filter with water containing amonium chloride and sulfide.

Manganese. The manganese is extracted from the precipitate on the filter by pouring through it strong H_2S water acidified with $\frac{1}{5}$ its volume hydrochloric acid (sp. gr. 1.11). This solution from the extraction is evaporated to dryness, ammonium salts are destroyed by evaporation with a few drop of sodium carbonate solution, hydrochloric acid and a drop of sulfurous acid are added to decompose excess of carbonate and to dissolve the precipitated manganese, and the latter is reprecipitated at boiling heat by sodium carbonate after evaporating off the hydrochloric acid. The manganese is weighed as Mn_3O_4 and calculated to MnO_2, in which form it is probably present in the enamel.

The residue of cobalt sulfide left after extracting the manganese is burned in a porcelain crucible, dissolved in aqua regia, and evaporated with hydrochloric acid; the platinum—and copper if any is present—are thrown down by heating and passing in hydrogen sulfide. The filtrate from the platinum and copper is made ammoniacal, and cobalt is thrown down by hydrogen sulfide. This is filtered

off and washed with water containing ammonium sulfide. This is either ignited and weighed as oxide or more accurately determined by dissolving in an ammoniacal solution of ammonium sulfate, containing 10 grams of ammonium sulfate and 40 cc. of concentrated ammonia for each 0.3 grams of cobalt, and electrolyzing in a weighed platinum dish at room temperature with a current of 0.5 to 1.5 ampere, and an electromotive force of 2.8 to 3.3 volts. The electrolysis is finished in three hours. The circuit is broken and the liquid poured off, and the platinum dish is washed with water, then with absolute alcohol (distilled one hour) and finally with ether, allowed to dry in oven at 95° for one minute and then weighed. The metallic cobalt is calculated as CoO, in which form it is present in the enamel.

The Determination of Boric Anhydride in Enamel.

The boron is determined in a separate sample of about 0.3 grams. This finely pulverized sample is fused with three grams sodium carbonate for fifteen minutes, is taken up with thirty cc. dilute hydrochloric acid and a few drops of nitric acid. The melt is heated in a 250 cc. round-bottomed flask almost to boiling, and dry precipitated calcium carbonate is added in moderate excess. The solution is boiled in the flask after it has been connected with a six-inch worm reflux condenser. The precipitate is filtered on an 8 cm. Buchner[1] funnel, and is washed several times with hot water, taking care that the total volume of the liquid does not exceed 100 cc.

The filtrate is returned to the flask, a pinch of calcium carbonate is added and the solution is heated to boiling to remove the free carbon dioxide. This is best done by connecting the flask to a suction pump, and the suction is applied during boiling. The solution is cooled to ordinary

[1] See Method of Wherry and Chapin, Jr., Am. Chem. Soc. 30, p. 1688, for Determination of Boron in Silicates.

temperature, filtered if the precipitate has a red color, and four or five drops of phenolphthalein is added and N/10 sodium hydroxide solution is run in slowly until liquid has a strongly pink color. A gram of mannite (or 150 cc. of neutral glycerol) is added, whereupon the pink color will disappear. Continue to run in N/10 sodium hydroxide until end point is reached. Add more mannite or glycerol and if necessary more alkali, until a permanent pink color is obtained.

1 cc. N/10 Sodium Hydroxide = .0035 g. B_2O_3.

Lead. The enamel for cooking utensils should never contain lead. To determine whether a cooking utensil contains lead, E. Adam gives the following simple qualitative method: A small piece of filter paper moistened with hydrofluoric acid is placed upon the enamel and allowed to remain for some minutes; the paper, together with any pasty mass adhering to the enamel, is then washed off into a small platinum basin, diluted with water, and tested for lead by passing H_2S through the solution.

J. Grünwald (Oesterr. Chem. Ztg. 8, p. 46) gives another quick test for lead: Wet small portion of surface with HNO_3 (conc.) and heat until acid is evaporated. Add several drops of water and a few drops 10% potassium iodide solution, and if even a trace of lead is present yellow lead-iodide will be produced.

Determination of Phosphoric Anhydride in Enamel.

Enamels containing bone ash to give opaqueness are analyzed for P_2O_5 as follows:

To a gram sample of very finely pulverized enamel in a platinum crucible one cc. of sulfuric acid is added and the crucible is filled half full (about ten cc. are required) with hydrofluoric acid. The crucible is heated on the water bath until most of the solution is evaporated and then gently on a hot plate to remove all the fluorine as

silicon-tetra-fluoride and as hydrofluoric acid, but no sulfuric acid fumes should evolve, as P_2O_5 is volatile. The residue is dissolved in nitric acid and taken to dryness, moistened with nitric acid, diluted with water, filtered and washed with a very little water.

Add aqueous ammonia to the solution from above until the precipitate of calcium phosphate first produced just fails to redissolve, and then dissolve this by adding a few drops of nitric acid. Warm the solution to about 70°C. and add 50 cc. ammonium molybdate solution (70g. MoO_3 per liter). Allow the mixture to digest at 50° for twelve hours. Filter off precipitate washing by decantation with a solution of ammonium nitrate made acid with nitric acid.

The precipitate on the filter is dissolved by pouring through it dilute ammonia solution (one volume of 0.96 sp. gr. ammonia to three volumes of water).

The solution is received in the beaker containing the bulk of the precipitate, all of which is dissolved in the ammonia solution.

An excess of magnesium ammonium chloride ("magnesia mixture") solution is added very slowly and with constant stirring. Let solution stand over night. Decant clear solution through a filter and wash by decantation with ammonia water (1:3). Dissolve the precipitate by pouring a little hydrochloric acid (sp. gr. 1.12) through the filter, allowing the acid solution to run into the beaker containing most of the precipitate. When all the precipitate on the filter and in the beaker is dissolved wash the filter paper with a little hot water. To the solution add 2 cc. magnesia mixture and then strong ammonia, drop by drop, with constant stirring until distinctly ammoniacal. Stir several minutes then add strong ammonia equal to one-third of the liquid, let stand two hours and filter off the precipitate of magnesium ammonium phosphate. Wash with dilute ammonia water, dry the precipitate, ignite separately from the filter, first at low temperature and

gradually raise to full blast. Weigh precipitate as $Mg_2P_2O_7$ and calculate as P_2O_5 in sample.

PART II.

THE ANALYSIS OF ENAMEL RAW MATERIALS.

The Analysis of Borax.

Sampling. A handful is taken from the middle of every tenth bag as it is unloaded. The sample from the entire car-load is then quartered down to two pounds. This is crushed so that it will pass through a forty mesh sieve. This is further quartered to about thirty grams. Sample is then accurately weighed and thoroughly dissolved in about 600 cc. hot—not boiling—water in a liter volumetric flask, and when cool is diluted to the mark. One hundred cc. of this, representing one-tenth of the sample, is then taken for analysis.

Determination of Sodium Oxide and Boric Acid. Titrate with normal sulfuric or hydrochloric acid solution, using methyl orange as indicator.

Number cubic centimeters Normal Acid $\times$ .031 = g, Na_2O. The solution is now boiled, covered with a watch glass to expel CO_2, and on cooling may turn pink. Add normal KOH solution (a drop will do) to bring back yellow color. At this stage all the boric acid exists in a free state.

$$(2Na^+ + B_4O_7^{--}) + H_2O + (2H^+ + 2Cl^-) = (2Na^+ + 2Cl^-) + 4(H^+ + 4BO_2^-)$$

Add as much neutral glycerol as there is solution (about 150 cc.) and titrate with normal potassium hydroxide, using phenolphthalein as indicator. If end is not distinct add more glycerol and more indicator.. The addition of glycerol causes the boric acid to become more dissociated, probably due to the formation of boroglyceric acid, and the end-point is quite distinct. The following equation represents essentially what takes place:

$$(4H^+ + 4BO_2^-) + (4K^+ + 4OH^-) = (4K^+ + 4BO_2^-) + 4H_2O.$$

1 cc. normal KOH solution = .035 g. B_2O_3.

If the analysis gives more Na_2O than is required to calculate all the B_2O_3 to $Na_2B_4O_7$, the remainder comes from sodium carbonate with which it has been adulterated.

Calculation of Results. The analysis of the borax is very important, as many times samples are adulterated, and even when not adulterated seldom contain exactly enough water to give the formula $Na_2B_4O_7 \cdot 10H_2O$. It is necessary to know the strength of the borax not only to buy intelligently, but also so that each and every mix of enamel will contain the same amount of borax.

It is customary to calculate from the percent of B_2O_3 in sample the percent strength of the sample as $Na_2 \cdot B_4O_7 \cdot 10H_2O$.

$$\%B_2O_3 \times 2.7307 = \%Na_2B_4O_7 \cdot 10H_2O.$$

When the sample has dehydrated of course this will run over 100%, and thus the correspondingly fewer pounds of borax may be used in the mix of enamel.

Moisture. On account of the large amount of water of crystallization in borax it is difficult to determine the moisture directly, therefore it is calculated by subtracting the % $Na_2B_4O_7 \cdot 10H_2O$ and the % Na_2CO_3 (if any is present) from 100%.

The Analysis of Ground Sand, Flint and Quartz.

Fineness. These, as are most of the raw materials used in the enamel, are tested for fineness. One kilogram is weighed on balance sensitive to 1/10 gram and is shaken on a 100 mesh sieve. The material remaining on the sieve is weighed. This is then shaken on an 80 mesh sieve and the residue weighed. From this is calculated percent through 100 mesh and percent through 80 mesh. The finer the material the better it is for use in making enamel.

An analysis for SiO_2, Fe_2O_3 and MgO is run when a new material is being tried, but generally only the SiO_2 and Fe_2O_3 are determined. In this case the acid solution from the silica is reduced by passing through a Jones Reductor and is titrated with N/10 potassium bichromate.

Preparation for Analysis. The material is carefully sampled by quartering down to several grams. This is ground in an agate mortar to pass completely through a hundred mesh sieve. This grinding is generally done by hand but an enameling works laboratory should be equipped with a McKenna Grinder, (manufactured by McKenna Bros. Brass Company, Ltd., of Pittsburgh), in which the material can be ground in an agate mortar by power.

The method followed for the analysis of flint and other forms of silica as well as clays and feldspars, is in all essentials, a well known method given by Hillebrand in analysis of silicate rocks, U. S. Geological Survey Bull. 305, and for reasons of space this method will not be given here.

The Determination of Titanium in Enamels, Clays and Silicate Minerals.

Titanium is determined after the determination of the iron by titrating with permanganate. This solution (after titrating) is diluted to 1000 cc. and is treated with hydrogen peroxide and the titanium determined by A. Weller's Colorimetric Method,[1] from one-half the solution.

This determination depends upon the fact that acid solutions of titanium sulphate are colored intensely yellow when treated with hydrogen peroxide; the yellow color increases with the amount of titanium present and is not altered by an excess of hydrogen peroxide. On the other hand, inaccurate results are obtained in the presence of hydro-fluoric acid (Hillebrand); consequently it is not permissible to use hydrogen peroxide for this determination which has been prepared from barium peroxide by means of hydrofluosilicic acid. Furthermore, chromic, vanadic, and molybdic acids must not be present, since they also give colorations with hydrogen peroxide. The presence of small amounts of iron do not affect the reac-

[1] Berichte 15, p. 25-93.

tion, but large amounts of iron cause trouble on account of the color of the iron solution. If, however, phosphoric acid is added to the colored ferric solution it becomes decolorized, and from such a solution the determination of titanium offers no difficulty. The solution in which the titanium is to be determined must contain at least 5 per cent. of sulfuric acid; an excess does not influence the reaction. The reaction is so delicate that 0.00005 gm. of TiO_2 present as sulphate in 50 cc. of solution give a distinctly visible yellow coloration.

For this determination a standard solution of titanium sulfate is required. This can be prepared by taking 0.6000 gm. of potassium titanic fluoride which has been several times recrystallized and gently ignited (corresponding to 0.2 gm. of TiO_2). This is treated in a platinum crucible several times with a little water and concentrated sulfuric acid, expelling the excess of acid by gentle ignition, finally dissolving in a little concentrated sulfuric acid and diluting with 5 per cent. sulfuric acid to 100 cc. One cubic centimeter of this solution corresponds to 0.002 gm. TiO_2.

The determination proper is carried out in the same way as the colorimetric determination of ammonium in the sanitary analysis of water.

50 cc. of the solution which has been brought to a definite and accurately measured volume is placed in a Nessler tube beside a series of other tubes, each containing a known amount of the standard titanium solution, filled up to the mark with water and each treated with 2 cc. of 3 per cent. hydrogen peroxide[1] (free from hydrofluoric acid). The color of the solution in question is compared with the standards. This method is only suitable for the estimation of small amounts of titanium, as the shades of strongly colored solutions cannot be compared accurately.

[1] The hydrogen peroxide solution is prepared shortly before using by dissolving commercial potassium percarbonate in dilute sulfuric acid.

The Analysis of Oxide of Tin.

Stannic Oxide. As this is one of the most important and most expensive of the raw materials used in enameling, an analysis is very necessary. The oxide is bought to contain not less than 99.5% SnO_2, and in this the impurities will consist of minute traces only of other materials. For an oxide of this kind from .2 to .3 of a gram of the sample is placed in a porcelain casserole, about 10 cc. of C. P. nitric acid of a sp. gr. 1.2 is added and the solution is slowly evaporated to a volume of about 2 or 3 cc., diluted to about 30 or 40 cc. of water, kept warm for about a half hour, filtered on a small blue-ribbon filter paper, and washed with warm water, slightly acidulated with nitric acid, being careful to avoid letting the precipitate creep up.

The precipitate is dried on filter paper in the funnel by placing in a hot air bath. The dried tin oxide is then removed as completely as possible from the filter paper and the paper is ignited in a porcelain crucible, being sure that there is an excess of air so that there will be no metallic tin reduced.

The balance of oxide of tin is now added to the crucible and the whole is moistened with a drop of nitric acid, the temperature under the crucible is gradually raised until it comes to a bright red heat over the blast flame.

This method gives results which check within one-tenth of a per cent.

Some brands of oxide of tin on the market contain a number of impurities in considerable quantities. Lead, iron, silica, sodium chloride, sodium sulfate and water are the most common of these. These are determined as follows:

Direct Method. Methods for the direct determination of the tin have proven quite unsatisfactory but the following, with very careful manipulation, yields results checking within 0.2%:

Five-tenths grams of oxide is mixed in a porcelain crucible with 3 grams each of powdered sulfur and dry

carbonate of soda, which both of course must be C. P., especially free of metals and earths. The covered crucible is heated for about an hour at *low heat first,* and later at the heat of a regular Bunsen burner; then let cool without lifting the cover. The cold mass is dissolved in water, filtered and washed with water to which was added a little sulfide of ammonia; the residue is brought back in the crucible and the melting process repeated, of which the solution is filtered to the first melting. The sulfide tin solution then is acidulated with hydrochloric acid and the precipitated sulfide of tin is allowed to settle clearly, after which it is filtered and washed with sulfide of hydrogen water.

The wet precipitate of sulfide of tin is transferred to an Ehrlenmeyer flask and treated with dilute hydrochloric acid and bromine until completely dissolved, at a low heat. The filter left after the solution is filtered off is washed and the $SnCl_2$ solution is precipitated with ammonia and a little nitrate of ammonia, allowed to settle, filtered and washed. After drying, the precipitate is ignited at white heat and is weighed as SnO_2.

Reduction Method. When the qualitative analysis shows no metal other than tin present, a very satisfactory method is to reduce a weighed quantity of the sample in a Rose crucible by heating to redness in a stream of hydrogen. The silica, if any is present, may be determined by dissolving out the tin with hydrochloric acid and weighing the residue.

Combined Water. In oxides which are prepared by certain precipitation methods, the combined water runs as high as ten per cent. To determine this, a two gram sample is heated in a porcelain crucible at a white heat to constant weight. The loss is combined water.

Lead. The lead is determined from the nitric acid solution and washings from the tin oxide determination by precipitation as the sulfate.

Iron. Digest about one gram with twenty-five cc.

of concentrated hydrochloric acid. As much water is added and the solution is boiled for five minutes. The residue is filtered off and about a cubic centimeter of concentrated sulfuric acid is added and the solution is evaporated until the sulfuric fumes come off. The solution is diluted, passed through a Jones Reductor and titrated with N/10 potassium permanganate solution.

Soluble Salts. About two grams of the sample is boiled with water for thirty minutes. The residue is filtered on a blue-ribbon paper and is dried in an air bath. It is then separated as completely from the paper as is possible. The paper is burned in a platinum crucible. A drop of nitric acid is added and the crucible is raised to bright red. The whole of the residue is now added and heated to white heat for some time. (If there was combined water present in the sample of course it will be driven off, and this must be taken into calculation).

The loss in weight (minus the above correction) is the soluble salts—usually sodium chloride and sulfate.

If desired these may be determined definitely by usual methods. (Titration of an aliquot part with N/10 silver nitrate solution for the chloride and precipitation of the sulfate as barium sulfate in another aliquot part slightly acidifies with nitric acid.)

Silica. To the residue in the platinum crucible from the above determination several drops of sulfuric acid are added, and the crucible is filled within a quarter of an inch of the rim with pure hydrofluoric acid. This is volatilized, carrying with it any of the silica as hydrofluosilic acid. Loss of weight = SiO_2.

The Analysis of Pyrolusite.

Pyrolusite has two uses in enamel, first as an oxidizing agent, and second to give an amethyst color to the enamel frit. Its grading, however, is generally made on its oxidizing value. This is found as follows:

Manganese Dioxide. A sample is carefully taken

from each barrel of the shipment, and after quartering down to about ten grams is ground so as to pass through a 200 mesh sieve. (It is better to test this by seeing if any grit can be detected when the powder is placed between the teeth.) The sample is dried, spread out on a watch glass, at 110° for one hour, transferred to a stoppered weighing tube, and after weighing, about one-half gram is transferred into a 250 cc. Ehrlenmeyer flask. For each gram of sample weighed out add at least 0.9 grams *pure,* tested oxalic acid ($H_2C_2O_4 \cdot 2H_2O$) weighing the acid accurately and recording the same. Add about 30 cc. of water and 30 cc. 5 normal sulfuric acid and drive off carbon dioxide by heating gently.

It is seldom necessary to filter after some practice, so the solution is titrated hot for the excess of oxalic acid with N/10 potassium permanganate solution. Calculate amount of oxalic acid oxidized by the pyrolusite. The reaction is

$$MnO_2 + H_2C_2O_4 \cdot 2H_2O + H_2SO_4 = MnSO_4 + 2CO_2 + 4H_2O.$$

Each gram oxalic acid oxidized therefore corresponds to .6902 g. MnO_2.

As pyrolusite is added to some enamels only to give color it is sometimes necessary to know its coloring power, and this is dependent upon the total manganese.

Total Manganese. One-half gram sample is boiled with strong hydrochloric acid until chlorine ceases to be evolved. The solution is neutralized with calcium carbonate and an *excess* of a strong *filtered* solution of bleaching powder is added. The solution is boiled until deep red, then alcohol is added until the red color disappears. The whole of the manganese now exists as MnO_2 and may be reduced with oxalic acid and titrated for its oxidizing power as before with N/10 permanganate of potassium. Each gram oxalic acid oxidized corresponds to .4361 g. Mn.

The Analysis of Soda Ash and Pearl Ash.

Generally it is only necessary to determine the total alkali in a sample of either soda ash or pearl ash, and to calculate from this the percentage of Na_2O or K_2O. A more complete analysis includes the determination of insoluble matter, iron, chloride, sulfate and moisture, as well as the total alkali.

Insoluble Matter. 50 g. weighed on rough balance (sensitive to 0.1 g.) and sufficient water added to dissolve the ash, shaking until dissolved. After an hour's digestion the solution is filtered through a weighed Gooch crucible with a circle of filter paper covering the bottom. This is dried at 105° and the increase in weight is insoluble matter.

Iron. The iron in the above insoluble matter is dissolved by pouring hot dilute hydrochloric acid through the precipitate in the Gooch crucible. The iron is precipitated from this by ammonium hydroxide and filtered on a white ribbon filter paper. The still moist precipitate is dissolved in sulfuric acid, reduced by means of a Jones Reductor and titrated with N/10 permanganate.

Chloride. Three gram samples are dissolved in water and nitric acid added until the solution is neutral (test with litmus paper). It is then titrated with N/10 silver nitrate solution.

Sulfate. Five or ten grams are dissolved in hydrochloric acid and the sulfate precipitated from the almost boiling solution by the addition of hot barium chloride solution.

Total Alkali. Twenty-five grams are dissolved in water in a 500 cc. volumetric flask and 50 cc. are titrated with N. hydrochloric acid, using methyl orange as indicator.

Hydroxide. To 50 cc. from above, precipitate all the carbonate with barium chloride. Without filtering, add phenolphthalein and titrate until colorless with normal hydrochloric acid.

Moisture. Ten gram samples are dried at 120° for two hours.

The Analysis of Saltpeter and Chili Saltpeter.

Moisture. Ten gram samples are heated to constant weight in an air-bath at 130°.

Insoluble Matter. Twenty grams are dissolved in boiling water and filtered through a weighed Gooch crucible with a circle of filter paper on the bottom. After drying at 110° in air bath to constant weight, the increase in weight is the insoluble matter.

Chlorine. The solution from above—this should be about 500 cc.—is placed in a 1000 cc. volumetric flask and 25 cc. (representing 0.5 g. sample) is titrated with N/10 silver nitrate, using potassium chromate as indicator. The result is calculated to sodium chloride.

Sulfate. Twenty cc. are heated to boiling and precipitated by adding hot barium chloride solution, a drop at a time and with constant stirring. After two hours digestion (or until precipitate settles quickly after agitating), filter through a Gooch crucible with ignited asbestos filter, ignite and weigh as barium sulfate. This is calculated to calcium sulfate.

Calcium and Magnesium. From five hundred cc. of the above solution (equal to 10 grams sample) at boiling temperature precipitate the calcium as oxalate by the addition of ammonium oxalate, being careful not to add much excess, as magnesium is to be determined in the same sample. Filter on a white ribbon filter paper, after an hour's digestion on the steam bath, ignite wet paper in platinum crucible, gradually increase to full blast and heat to white heat to constant weight. Weight as calcium oxide.

Determine the magnesium in filtrate from the calcium by addition of a solution of microcosmic salt and afterward one-third the volume of concentrated ammonium hydroxide, added drop by drop. The precipitate, ignited

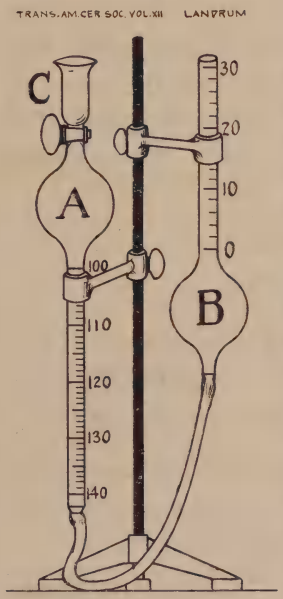
separate from the filter paper, is heated at first gently and at last with the full heat of a Bunsen burner, and weighed as magnesium pyrophosphate ($Mg_2P_2O_7$).

Perchlorate. Ten grams of the sample of which the chloride content has already been determined, is mixed with an equal quantity of chemically pure sodium carbonate, and is heated in a large, covered, platinum crucible to quiet fusion. Ten or fifteen minutes are required. The product is then dissolved in nitric acid and the chloride estimated as usual.

Nitrogen. This is determined by the Kjeldahl method after reducing the nitrate to ammonia. Twenty grams of the sample are ground coarsely and dissolved in water in a liter flask, and solution is diluted to the mark. Twenty-five cc. (equal to 0.5 g. sample) of this solution is mixed in a 800 cc. Kjeldahl flask with 15 cc. concentrated sulfuric acid to which 2 grams salicylic acid have been added, then add gradually 2 grams zinc dust and shake flask to mix contents. Digest over low flame with neck of flask slightly inclined until danger of frothing has passed. Increase flame until the acid boils briskly and until white fumes cease to come off. This usually takes about ten minutes.

Add .7 gram mercuric oxide and continue boiling, adding acid if necessary to keep solution from solidifying. Solution should be clear in a short time. Complete oxidation by adding a little powdered potassium permanganate and allow the contents to cool. Add about 200 cc. ammonia-free water and 25 cc. potassium sulfide solution (40 g. commercial salt to the liter) and shake thoroughly. Add several pieces of granulated zinc and then pour carefully down the side of the neck 100 cc. sodium hydroxide solution (500 g. per liter), avoiding shaking and thereby mixing the acid and alkali. After washing the neck with ammonia-free water connect the flask immediately with a previously set up block tin condenser, which has been thoroughly washed and the tips of whose delivery are im-

mersed in 30 cc. standard acid solution (half normal), colored with methyl orange contained in a 150 cc. Phillip's flask. Mix contents of digestion flask by shaking thoroughly, then heat carefully, then slowly (taking about an hour) distill over 200 cc. of the liquid. Titrate excess of acid with standard half normal alkali solution, and from this calculate percentage of nitrogen in sample.



Lung Nitrometer Method. Where frequent analyses are made the Lung[1] Nitrometer method is better. A nitrometer modified especially for the use of the determination of nitrate in saltpeter is here illustrated. The Nitrometer "A" and the leveling tube "B" are filled with mercury. From a twenty gram sample which has been dried at 110° to constant weight as nearly as is possible 0.35 grams is put into a weighing tube. This is then accurately weighed and the contents shaken into the entry tube "C." The weighing tube is again weighed and the difference in weight is the grams sample employed. This should be close to 0.35 grams so that the gas evolved will be more than 100 cc. and less than 130 cc. at ordinary temperature and pressure.

About .5 cc. water is then poured in and the solution and crystals (after a minute's standing) are drawn into the measuring tube by opening the three-way cock into the entry tube "C" and lowering the leveling bulb cautiously. The cup is washed, using less than 1 cc. of water, and about 15 cc. of strong sulfuric acid is admitted through the entry tube into the measuring tube. (More than 1½ cc. H_2O renders the acid too dilute, and the

[1] Berichte 1885, 18, 1391.

mercury is attacked). After the cock is closed the leveling tube is placed in a clamp, the measuring tube is thoroughly shaken and the following reaction takes place:

$$NnO_2 + H_2C_2O_4 : 2H_2O + H_2SO_4 = MnSO_4 + 2CO_2 + 4H_2O.$$

The measuring tube is now placed in clamp on a level with the levelling tube and solution is allowed to cool for an hour.

The tube is then accurately leveled, allowing one division of mercury for each six and one-half divisions of acid, and the gas volume read off. The temperature and barometric pressure are read and the gas corrected to standard conditions. Each cc. NO gas corresponds to .0037986 g. $NaNO_3$ or .003845 g. KNO_3.

The Analysis of Cryolite.

Cryolite is a mineral occurring in large quantities in Greenland, and is the sodium salt of hydrofluo-aluminic acid, Na_3AlF_6. It is used in enamels and is fused, finely ground with the frit giving it a milky opaqueness which enamellers call "body." It is a very expensive material and is most always far from pure, either being deliberately adulterated or merely naturally impure.

Methods used by most chemists for its analysis are at the best crude. The direct determination of the fluorine is the only satisfactory means of properly grading it. The method used for cryolite is exactly the same as that employed in the analysis of fluorine-bearing enamel as given in the beginning of this article, except that one gram of the cryolite is finely ground with about three grams (accurately weighed) of pure silica, and this mixture is fused with about eight grams of equal parts of sodium carbonate and potassium carbonate. In determining the silica in the cryolite, this silica which has been added must be deducted from that found.

The alkalies are determined by the method of J. Lawrence Smith[1] from a gram sample finely powdered.

Combination of Results. All soda is combined with sufficient fluorine to form sodium fluoride (NaF_2). The remainder of the fluorine is combined with aluminum as aluminum fluoride (AlF_3). The remainder of the aluminum is calculated as alumina (Al_2O_3).

The Analysis of Fluospar.

Fluorspar is analyzed especially for its fluorine content by the same method as that given under Cryolite. It is a material seldom adulterated and a mere fusion with six times the weight of sodium carbonate, the taking to dryness with hydrochloric acid as in ordinary silicate analysis, the removal of iron and alumina as hydroxide with ammonia, and the precipitation with ammonium oxalate of the calcium and its final weighing as calcium oxide, is sufficient in most cases. All the calcium may be calculated as CaF_2. The determination of the fluorine, however, is of course the only exact method of accurately grading this material.

The approximate method for determining the fluorine is as follows:

Approximate Method for Fluorine. About one gram of sample finely ground and accurately weighed is intimately mixed in agate mortar with about the same quantity of pure silica. The whole is transferred to a 250 cc. Ehrlenmeyer flask—rinsing the mortar with more silica. The flask is weighed and a weighed quantity of concentrated sulfuric acid is added. The record should now show the weight of flask, silica and acid. The flask is gently heated and the loss of weight is calculated as silicon fluoride.

Iron. For use in light colored enamels the iron content of the fluorspar is important. Five grams, finely

[1] Am. Jour. Science (2) 50, p. 269. Treadwell-Hall Anal. Chem., Vol. II, p. 394.

ground, are heated in a platinum dish with an excess of sulfuric acid as long as hydrofluoric acid is given off.

After cooling it is diluted with 100 cc. of water, and after reducing by drawing through a Jones Reductor the solution is titrated with N/10 potassium permanganate solution.

Accurate Method for Fluorine. The fluorine may be accurately determined by the following method:

One gram sample (ground to pass through 200 mesh sieve) is mixed with three grams silica and three grams each sodium carbonate and potassium carbonate in a platinum crucible. *Heat gradually* until it is in quiet fusion. The thin liquid fusion soon changes to a thick paste or only sinters somewhat. The reaction is complete when there is no further evolution of carbon dioxide.

After fusion the melt is treated with water and after cooling the insoluble residue is filtered off and thoroughly washed. The solution contains all fluorine and considerable silica. Remove the silica by adding four grams solid ammonium carbonate. Heat liquid at 40°C. for some time and let stand over night. Filter in morning and wash with ammonium carbonate water.

Evaporate on water bath almost to dryness in platinum dish (keep covered, as liquid foams). Dilute with a little water. Add a few drops of phenolphthalein. Add dilute HCl until colorless. Heat on steam bath and color will return. Cool and repeat operation until 1.5 cc. double normal HCl is sufficient to make colorless. Remove last traces silica by treating the solution with a solution of moist zinc oxide in ammonia water. Boil until ammonia is completely expelled. Filter off silica and zinc oxide and wash with water.

Precipitate fluorine as calcium fluoride and calcium carbonate by adding an excess of calcium chloride. Filter, using blue ribbon paper, and wash thoroughly with hot water. Dry precipitate on funnel. Transfer as much as possible to a platinum crucible. Burn filter and add ash. Ignite contents of crucible.

After cooling the mass is covered with a slight excess of dilute acetic acid (this changes the calcium oxide to soluble acetate.) Evaporate to dryness on steam bath. Take up with water. Filter, wash and dry. Transfer most of precipitate to weighed platinum crucible. Burn filter paper. Add ash. Ignite and weigh as calcium fluoride, CaF_2. To confirm the results add cautiously little concentrated sulfuric acid. Evaporate off excess sulfuric acid, ignite and weigh as calcium sulfate.

The Analysis of Oxides of Antimony.

Arsenic. One gram of oxide of antimony is dissolved in 10 cc. of strong hydrochloric acid—at as low a temperature as possible. The solution is then cooled and packed in ice and the arsenic, which is almost invariably present, is removed by passing through H_2S for several hours. The As_2S_3 is filtered off in a weighed Gooch crucible, washed first with CS_2 and alcohol then with concentrated hydrochloric acid and dried at 100°, and weighed as As_2S_3.

Antimony. The filtrate from above is put into 250 cc. volumetric flask, rinsing the beaker well with concentrated hydrochloric acid and an equal part of water. All the H_2S is removed by passing through a current of air. Five grams of tartaric acid are added and the liquid diluted to the mark.

Twenty-five cc. of the solution are measured out with a pipette and are neutralized with dry sodium bi-carbonate—keeping covered to avoid loss—finally a pinch of sodium bi-carbonate and a cubic centimeter of clear starch solution is added and the mixture is titrated with N/10 iodine solution.

1 cc. N/10 Iodine = 0.0060 grams Sb.

The Analysis of Oxide of Cobalt.

Arsenic. One gram finely pulverized sample is fused at low heat with ten grams bisulfate of potassium for three

hours. The melt is extracted with water acidified with sulfuric acid and the arsenic is precipitated from the warm acid solution with H_2S, collected in a weighed Gooch crucible, washed with water containing H_2S and dried at 100° for one hour and weighed as As_2S_3.

Cobalt. The filtrate from above is boiled, and at the same time air is drawn through to remove the H_2S, and it is then treated by Fisher's Potassium Nitrite method[1] to separate the cobalt and the nickel.

The concentrated solution containing salts of both metals is treated with pure potassium hydroxide to alkaline reaction, made slightly acid with acetic acid, and to this a concentrated solution of pure potassium nitrite that has been made slightly acid with acetic acid is added. After vigorous stirring, the mixture is allowed to stand twenty-four hours in a warm place. Before filtering, a little of the clear solution is pipetted off and treated with more potassium nitrite to see if the precipitation of the cobalt has been complete. If a precipitate is formed, the whole solution is treated with more potassium nitrite and again allowed to stand until complete precipitation is effected. The precipitate is then filtered and washed with a barely acid 5 per cent solution of potassium nitrite until 1 cc. of the filtrate, after being boiled with hydrochloric acid and treated with caustic potash and bromine water, no longer gives a black precipitate of nickelic hydroxide. The cobalt precipitate is then transferred to a porcelain dish, covered, and hydrochloric acid is gradually added until there is no further evolution of nitric oxide, and after filtering, the cobalt is precipitated by means of caustic potash and bromine water.

The precipitate is filtered off, using blue ribbon filter paper, dried, and ignited. After cooling it is treated with water in order to remove the small amount of alkali which is always present, after which the residue is ignited in a stream of hydrogen and weighed as metal. After weigh-

[1] Treadwell, Vol. II, p. 130.

ing, the metal is disolved in hydrochloric acid, evaporated to dryness, the dry mass moistened with hydrochloric acid, then treated with water, and the small residue of silicic acid is filtered off. This residue is ignited and its weight subtracted from that obtained after the ignition in hydrogen.

Nickel. The filtrate containing the nickel is treated with hydrochloric acid until the nitrite is completely decomposed, and the nickel is precipitated with potassium hydroxide and bromine water as brownish-black nickelic hydroxide [$Ni(OH)_3$.]

The precipitate—which seldom contains more than ten milligrams of nickel—is washed with hot water, collected on a filter and is dried, ignited separately from the filter, and weighed as NiO, in which form it was probably present in the oxide.

Steel Plate.

The steel best adapted for enameled ware is of very low carbon value and extremely low in the other impurities, in fact, the nearer pure iron the better. Of the steel plate used by the Columbian Enamelling and Stamping Company, the best satisfaction was obtained from those giving the following analysis:

Sulfur from .040% to .050%; phosphorous from .030% to .090%; silica less than .01%; manganese from .060% to .040%, and carbon less than 0.10%. The sheets must be of an even gauge for seamless drawn work and of a dark soft quality, which allows them to be drawn without tearing. When the vessel is made without drawing and sheets are used flat, this evenness of gauge is not so much of object. The grain in all cases must be as open as possible. The sheet must be low in carbon and sulfur, as these develop gases at temperatures of the muffle, which would cause the enamel to peel off.

Samples of the steel plate are obtained from drillings taken from eight or ten sheets stacked in a pile, and

drilled holes are run every two inches on the diagonal of the plate. Drillings are sampled down to twenty-five grams, which are kept in stoppered bottles. The method of analysis is that commonly employed by steel-works chemists, and can easily be found in print elsewhere, and for that reason will not be given here.

A PLEA FOR BONE CHINA.

BY

CHARLES F. BINNS, Alfred, N. Y.

This paper will, in some measure, depart from the form which has become usual in the proceedings of this Society, inasmuch as it will not advance experimental data in support of any claim or theory, but is intended to argue the case for Bone China as a product which is well worth the serious attention of American potters.

This ware has long been the staple of fine English services, and if America is to compete successfully with imported goods, something equally fine must be offered. Hotel china does not meet this demand. Some attempts have been made to decorate this ware and to place it before the buyers of high grade goods, and, while considered apart, it presents a fair appearance, when compared with the English product it loses caste.

The constitution of Bone China is too well known to need description. Hundreds of recipes are in the hands of American managers, and there is but little to choose between them. The main variation is found to be in the brand of clay used and in the substitution of feldspar for Cornwall stone. Mr. Bernard Moore, in the Transactions of the English Ceramic Society, (Vol. IV, p. 37) states that a normal china body consists of:

Bone Ash	44
Cornwall Stone	30
China Clay	26

and says that variations in the quality of the stone have led to a decrease in this ingredient and a corresponding increase in the clay.

Mr. Watts has presented to this Society an exhaustive treatise (Vol. VII, p. 204) on the Constitution of Bone

China Bodies, so that it is unnecessary to deal at length with this part of the subject. The main point of interest for American potters is whether a satisfactory substitution of feldspar for Cornwall stone can be made. Cornwall stone is, in some respects, a very objectionable material. The variations in composition are large, sometimes dangerously large, whereas native feldspars are remarkably uniform, provided, of course, that care be taken in the selection of the brand. Mr. B. Olsen (Eng. Cer. Soc., Vol. IV, p. 43) states that in Sweden feldspar is used in Bone China and that a whiter body is obtainable than from stone. The high content of quartz in Cornwall stone makes it necessary to use some flint in a body which depends upon feldspar, and flint must be used with care, as Mr. Watts has pointed out. On the other hand, feldspar permits the use of a higher content of clay, which is an advantage.

A good Bone China, using feldspar, may fall within the following range:

Bone Ash	42 to 32
Spar	15 to 19
China Clay	33 to 35
Flint	10 to 14

But after all, the successful manufacture lies not so much in the mix as in the manipulation. The custom, prevalent in this country, of purchasing materials ready for use and employing them in the mix without preparation, renders it necessary to insist that Bone China cannot be successfully manufactured without a change in the conditions. Mr. Watts ground his china mixtures for two hours on a small ball-mill, and while it may not be necessary to grind the whole mix, it is certain that the bone-ash, spar and flint must be finely ground, either separately or together, if a successful result is to be reached. The lawn used should be 16, or 160 mesh. The next point is the magneting of the slip. There is always a good deal of iron present in bone-ash, and it is a matter of common knowl-

edge that commercial flint and spar are never free from it. Iron specks in Bone China are more objectionable than in any other ware, not only because the pure white of the china is one of its chief beauties, but also because the bone seems to have the property of spreading the iron stain. A close examination of the iron specks in this ware shows that the minute, almost invisible black spot is surrounded by a brown halo, and this greatly enlarges a spot which otherwise would be almost unobjectionable.

There are many modern improvements in the process of magneting, but no method can be considered satisfactory which does not permit an examination of the last magnet passed by the slip so that an absolute freedom from iron may be assured. Most of the English plants adhere to the old plan of movable horseshoe magnets through which the slip is repeatedly run until the magnets show no iron at all.

The small percentage of clay in the batch, and a non-plastic clay at that, shows that the body is extremely short. Grinding the whole batch will help this because clay increases in plasticity on being ground in water, and in the process of grinding there is also secured a more intimate mixture of the particles. In the days of the slip-kiln in which the moisture was driven from the slip by heat the body was quite plastic enough for easy working, but the filter-press at once gave rise to trouble. The product of the press is never quite as plastic as that coming from the slip-kiln and when, as in the case of Bone China, there was only a small margin, the change gave rise to serious difficulty. A prolonged ageing of the clay gave considerable assistance, and it was also found advantageous to use a bone which retained a large proportion of carbon. The hard burned bone ash which alone is obtainable here does not show plasticity even when ground fine, much less if it be used in the commercial form.

The pug-mill cannot be successfully used in tempering a Bone China body. The action of the knives in cutting

the clay tends to make it short, but relief has been found in the use of the French rolling-table. The operation of this is to roll and knead the clay without cutting it and it is, beyond question, the best substitute for hand-wedging that has yet been devised. The nearest approach to this tool in common use is the wet-pan, which is extensively employed in the tempering of clay for sewer-pipe and similar products but this, being made largely of iron, would not be suitable for white wares. In the French machine the table and rollers are covered with zinc. The only objection to this device is that it is not continuous in action. The motion must be stopped about three times in an hour, the clay removed and a new charge fed.

The working of the Bone China body presents some difficulties. At one time it was thought that the hand tool was the only possible means of making flat, and some English factories still adhere to this belief, but the pull-down has been successfully adapted even to the finest of wares, and the way seems now clear for a fuller development of the machine method. The French have devised a plate-making machine for the production of hard porcelain, and the use of some such appliance for Bone China seems to offer an attractive proposition. Essentially, this machine is constructed with the idea that the way to make successful plates in a fine body is to pay especial attention to the bat. It is well known that it is the common practice of the batter-out to spread the ball into a bat by means of one or more heavy blows. The result is that the bat has no structure at all. It is simply a heterogeneous mass of particles which possess no form or arrangement. The English batting machine makes one step in advance of this, in that the bat is spun upon a revolving head, but there is no movement about a fixed center, that is, the center of the bat is not necessarily the center of the plate. The French machine remedies this, for the bat is spun upon a diaphragm, which is lifted entire and set in the machine concentric with the plate mold. Thus the movement of the

particles is made uniform from the first, and it is claimed that there is much avoidance of crooked ware.

Cups are either cast or made from thrown linings. The common method of the cup-maker will not answer. Pressing and casting are both employed for jugs and hollow-ware.

One of the vital points in the manufacture of Bone China is the placing for the biscuit fire. The English plan is to employ skilled placers, who do nothing but fill the saggers and setters. The carrying and setting in the kiln itself is done by cheaper labor. For flat ware setters are used, each piece having a compartment to itself. A shaped bed is made in burned flint, and upon this the plate or saucer reposes, either face up or inverted, according to shape. The ware needs the support of the bed, for there is a strong tendency to go out of shape in the hard fire. Cups are fitted with tapering rings, made from scrap clay, for the same reason. Old flint is used because of the well known expansion which takes place when flint is fired for the first time. In order to keep up the supply of old flint a little green flint is put into each kiln, being made use of in some way in which it can do no harm.

It has sometimes been found necessary to magnet the flint because a speck of iron in the bed will often be transferred to the ware in firing. The biscuit kiln heat ranges from cone 9 to cone 11, though Mr. Watts states that good china can be made as low as cone 8.

The glaze is a normal fritted glaze, of which the following is the formula:

.25 K_2O		
.30 CaO	.35 Al_2O_3	2.7 SiO_2
.29 Na_2O	.35 B_2O_3	
.16 PbO		

and which worked out into a batch is:

FRITT		GLAZE	
Spar	300	Fritt	32
Whiting	75	White Lead	5
Flint	112	Cornwall Stone	5
Kaolin	25	Kaolin	1
Borax	160		
Carbonate of Soda	30		

The fire is quite low, rarely exceeding the melting point of cone 1. In the glost placing much care must be taken. Bone china is valued according to the perfection of the glazed surface. Pins and stilts are never used. Plates and saucers are set in fireclay tripods known as angles, and for cups and hollow ware the sagger bottom is washed with a mixture of equal parts bone ash and flint. This forms an infusible coating, which flakes off if any should adhere to the foot of the piece. The glaze is liable to pinholing, and to avoid this it is important to cool slowly in the early stages.

Upon sorting the biscuit a good many crooked plates are found. These are straightened by an ingenious arrangement of fireclay rings. A ring, if broken, would show a V shaped cross section. The ring at the point of the V must be about one-eighth of an inch less in diameter than the plate to be straightened. A ring is set in the sagger point downward. The flat top is dusted lightly with flint, and a crooked plate is inverted upon it. A second ring is made to rest upon the plate so that the point just clips the edge. Upon this another plate, then another ring and so on. Thus each plate and ring press upon those below. A gentle fire is sufficient, in fact the great danger lies in over-firing, for the plates have now no bed of flint to protect them from the heat. Cone 6 is quite enough. The fitting of the rings and plates is important. If the ring is too large obviously it will not clip the plate at all. If too small it presses too far up the rim, and the plate is flattened. Cups do not often need straightening, but it can be accomplished by placing each upon a tapering fireclay ring.

These operations of course mean expense, but the value of the ware is greatly increased by successful straightening, and the loss of a few pieces is of less importance than the improvement of the large number. In other words, the profit in bone china is in superior quality.

Up to this point we have simply been laying a founda-

tion. Nobody expects to sell this ware undecorated. In fact, no price which could be obtained for the white ware would make bone china pay. We are expecting to sell fine table services, and the decoration can hardly be too rich. It may be questioned whether, among American manufacturers, the art of china decoration is fully appreciated. The blame for this largely rests with the foreign decorator who, content to draw the equivalent of ten dollars weekly in his own country, demands thirty or forty when he sets foot on these shores. The remedy lies in the training of native designers and decorators and the creation of an American type of ware, not because American decorators are worth less money but because they can do more work.

It is not the purpose of the writer to discuss styles or methods of decorative treatment, but to deal rather with technical processes, but it has been necessary to lead up to the question of decoration, because only by solving the problems connected therewith can a market be found.

It is only necessary to touch upon the matter of decoration, because it is upon the rocks and quicksands which abound in this stage of the manufacture that many hopeful ventures have been wrecked.

No one who has attempted to decorate bone china has escaped the evil of the "black foot." A dozen plates are decorated and burned. Upon drawing the kiln it is found that upon, perhaps, half of the number, the foot is gray or black. Sometimes this has been so bad upon a rich service that the foot of every plate had to be covered with solid gold. The immediate cause is contact with the hand of the decorator. The organic salts from the moist skin have penetrated the ware and turned black from the residue of carbon. The ultimate cause is a defective glazing of the foot of the plate, or a defective body caused by too coarse a material, or an insufficient biscuit fire. The latter is the most usual and the most easily prevented for, obviously, if a plate is to stand upon its own foot in the glost fire some little roughness is bound to result.

A second far-reaching evil is that known as "brown spot." Upon coming from the decorating kiln some pieces show patches of pale chestnut brown. This often appears on the surface but is more obvious by transmitted light. This phenomenon has been rather closely investigated in England by Mr. Bernard Moore and Dr. Mellor. (English Ceramic Society Transactions, Vol. IV, page 40.) Mr. Moore advances the opinion that iron phosphate in the ferric form is responsible for the stain, and that this substance, with the resulting brown color, is developed by the oxidation of ferrous phosphate. Dr. Mellor found green crystals present when the greenish stain appeared and brown crystals as the brown discoloration became evident. It is stated on the one hand that ware inclined to stain can be made brown or green at will, but Dr. Mellor affirms that the brown stain often shows upon ware which has not previously exhibited any trace of green. These investigators have also pointed out that when the china spits out in the decorating kiln the eruption seems to follow along the lines of the stain.

Whatever may be the immediate cause of the stain, Mr. Moore has proved that the ultimate cause is the use of what the English china makers call a "dry" stone. In other words, the ware which shows the stain is deficient in alkali and therefore somewhat porous. This coincides with the experience of the writer, but it has also been found that a similar porosity, with the consequent staining, is caused by lack of grinding. A bone china made with feldspar is less liable to this stain because with feldspar there is much less liability to variation in the content of potash.

The final question, and that which proves the practicability or otherwise of any enterprise, is "will it pay?" This is the touchstone to which every effort in the manufactory must be brought.

It is certain that the English potters make it pay and that they fill our finest stores with high-class goods. It is

also certain that domestic manufacturers can only capture this trade or any part of it with goods of equally high grade. It cannot be done with Belleek or Hotel China, nor even with Texas kaolin. Bone china is in a class by itself, and no other ware can successfully compete with it.

An English bone china dinner plate, undecorated, can not be laid down, duty paid, in New York, for less than 60 cents, and it is strange if with the characteristic pluck and resource of Americans this condition cannot be met.

It has already been pointed out that there is no advantage in selling white china, the above figure is quoted simply as a basis of comparison. To sell the ware white is like spending one's capital. The best white ware is the foundation for the richest decoration, and the richer the decoration the larger the profit, for the simple reason that twenty per cent on a dollar is ten times as much as the same percentage on ten cents.

These arguments are advanced in the cause of bone china as the best means of meeting foreign competition. To attempt the manufacture of French or German porcelain would be to revolutionize every process in the factory, but as all American technique has been derived from England, it is but one more step to take up and successfully produce this beautiful ware.

DISCUSSION.

Mr. Hope: I would like to ask Professor Binns down to what temperature it would be necessary to cool the glost kilns in order to avoid pin-holing?

Mr. Binns: I am not able to answer that in terms of temperature. My experience has been that if the kiln is cooled off too fast you get pin-holing. The heat should be held until the glaze has had time to settle down. The point is to secure the completion of any reaction that may have begun and may not be altogether finished at the time of stopping the fire. My practice has been, after a little ex-

perience with the kiln, to close the fire mouths when about one-half full, so that the fuel already there will be sufficient to finish the kiln, close the fire mouths and seal them and allow the kiln to finish itself, and then when the brightest red has passed off open up and cool fast.

Mr. Parmelee: Are there any peculiarities in the firing in the English practice, where the partially burned bone is used, which differ essentially from the American practice where the fully calcined bone ash is used? Of course, that partially calcined bone contains a considerable quantity of carbon, and also probably a good deal of CO_2, which is not driven off. Is there any difference in the kiln practice?

Mr. Binns: I have never noticed any difference at all. The only trouble is in the variation of the weight of the calcium phosphate on account of the varying contents of carbon. This is not very important, because the actual contents of calcium phosphate in the bone body may vary within certain limits. The difficulty is rather in the shrinkage of the ware. There is some difficulty in adjusting the shrinkage, particularly if a matching order comes in. If a cover has to be made, and the body is two sizes smaller than the one made, say five years ago, there is a difficulty. The difference in shrinkage is due very largely to the variation in the bone ash composition.

Mr. Stover: I would like to ask about the straightener sketched on the wall. Do I understand that you give a flat piece an extra fire on the straightener, and then turn it the other side up for the biscuit fire?

Mr. Binns: No, the crookedness does not occur until after the biscuit fire.

Mr. Stover: I was wondering whether this was an extra precaution.

Mr. Binns: No, the plates are straight when they are set for the first biscuit fire. When they come out of the kiln, they are found to be warped, not as much as most of your porcelain, but too crooked for bone china. The prob-

lem is to straighten them and they are set in this apparatus, put into another kiln and burned again. Then they come out for the most part perfectly straight.

Mr. Stover: Do you ever have whirling?

Mr. Binns: No, the tendency is the other way.

Mr. E. C. Thomas: Do you take the same precaution in cooling the biscuit kiln that you do in the semi-porcelain? We usually daub the kilns up to keep the entrance cooling.

Mr. Binns: I have never found that necessary. In fact, my practice is so limited that I am scarcely fitted to make the comparison with semi-porcelain. No such precaution was ever taken in bone china. My impression is that this ware stands changes of temperature better than most vitrified ware.

THE CHEMIST AND THE GLASS MANUFACTURER.

BY

ALEXANDER SILVERMAN, Pittsburg, Pa.

For a number of years it has occurred to the writer that of all manufacturers the glass manufacturer seems least prone to take advantage of valuable assistance the chemist has in his power to render. This power is naturally latent in most cases, but by proper co-operation on the part of manufacturer and chemist it could be made active and exceedingly valuable.

A few notes on the experiences of and results accomplished by a young chemist, employed for about one and one-half years in a factory where a large variety of glass was manufactured, will best serve as examples. This young man was one of ordinary ability, only, and while trained as a chemist had only that very limited knowledge of glass manufacture which can be gleaned from text books on introductory chemistry. In addition he had perhaps made a glass analysis or two.

September after graduation found him called to the factory already mentioned, where he was taken to a little four by six room located in the basement, adjoining the mixing room, and told to establish and take charge of a chemical laboratory. The fallacy of this was, of course, evident to even a man of so little experience. He therefore immediately sought out the president of the company and succeeded in convincing him of the necessity of locating a laboratory and purchasing equipment. The chemist chose as a location a space next to the offices, and about the cleanest place in the plant. The superintendent was consulted and, never having employed a chemist, was perhaps somewhat suspicious, and finally succeeded in locating the laboratory next to his office in the mixing room, where

soda ash and lime dust were constantly flying about. The floor of the laboratory was over a large open space, at one time used in connection with a producer gas plant but then filled with stagnant water. The ceiling consisted of brick arches, as it formed the floor of the factory above. A wooden ceiling was desired but not furnished, so instructions were left to paint walls and ceiling with zinc white, and the chemist left for several days to secure apparatus and chemicals necessary for equipment. A small still was asked for, but through the superintendent's influence the chemist was compelled to use condensed steam from the power plant. On returning the chemist found his laboratory white washed instead of painted. This he bore until dropping of plaster particles into beakers and crucibles became so frequent and spoiled so many analyses, that the president of the company finally ordered a modern ceiling installed. It was soon evident that steam from the power plant could not be used, so after purchasing distilled water for six months and finding its cost in excess of the still originally asked for this, also, was installed.

The first problem given the chemist was the production of a cloudy glass which would transmit subdued light without a fiery glare, and yet have a glossy surface. Several other kinds were already manufactured, but not as desirable. These were (1) glass whose surface had been etched with hydrofluoric acid, (2) sand-blasted glass, and (3) clear glass cased with opal. The first two of these had a dull surface on which dust accumulated, giving it a gray appearance, and the third imparted a fiery glare to the light. Besides, neither of these transmitted sufficient light, and each type required double handling in manufacture. The chemist was instructed to carry on this research work under the superintendent, who had already been trying two years to obtain the desired result. The superintendent would use clear glass batches, whose composition was unknown to the chemist, and the chemist had to recommend material to be added for the production of the de-

sired cloudy effect. This state of affairs continued fruitless for about six months, when the chemist demanded the composition of the clear glass batch if he were to continue work on the problem. It was given him, and suffice it to say that in another six weeks he had produced this glass which for the past five years has been in demand for special lighting purposes, and were its properties better known it would generally displace etched, sand-blasted and opal glass. More light is transmitted than by either of the other varieties, the light is more nearly white and the appearance of the glass is decidedly pretty. A word regarding advantages to the manufacturer. The batch is workable after a short melting period, the glass has a high polished surface, and the slight difference in cost of raw materials more than counterbalances the cost of double handling involved in manufacture of either of the other three types mentioned.

Another branch in which this young chemist proved valuable was in the silvering department, where from twenty to twenty-five reflectors were produced weekly. The superintendent had been in charge of this department prior to the advent of the chemist, and his directions were "add a certain number of quarts of ammonia to a certain number of pounds of silver nitrate." The ammonia was kept in an open carboy, thereby constantly losing strength. It was measured in an open graduate and produced an almost unbearable atmosphere. The chemist's first step was to conduct the ammonia into the bottom of the silver nitrate solution by means of a syphon, the lower end of which was used as a stirrer through a rubber connection. He was thus able to secure a definite end-point and always have his silvering solution uniform, at the same time working in an atmosphere in which the odor of ammonia was hardly perceptible. After a little experimentation he found it possible to silver 26,000 reflectors perfectly from the same amount of silver formerly used for 18,000. The plant had for years turned out a number of spotted reflectors. The

cause of this was discerned and the trouble entirely eliminated.

Through the analysis of raw materials used in glass manufacture a glass of more constant composition resulted. Lime, on being heated over the blast lamp, was found to contain from twelve to thirty-two percent of volatile matter, depending on the shipment or length of time it remained in storage in the plant. Pearl ash, which readily absorbs moisture, had also to be corrected constantly.

In the plant referred to four or five types of glass were commonly worked. As there were generally about twenty of the fifty pots in use, it was necessary to check the glass so that no mistakes be made. The lone chemist found it impossible to conduct twenty such analyses daily, so he determined the specific gravity, and found that there was sufficient difference between the types to check each by its specific gravity. For this purpose a small piece of glass about the size of the first two joints of one's little finger was gathered from each pot, and the specific gravity determined by weighing in water and in air. This could be done in several minutes, thus affording a rapid check on composition.

These are a few of the things this young chemist accomplished, though entrusted with the formulae of but two or three of the twelve or more batches mixed at that plant. At the end of about a year and a half he was dismissed because the company did not feel it could afford to increase his salary. What could not this young man have accomplished had he been given greater confidence by the firm employing him? Instead he drifted into other lines, as few glass manufacturers at that time employed chemists.

In the writer's mind, many important improvements would result were chemists more universally employed in glass factories. Expensive chemicals at present enter into the batch which might be partly or wholly eliminated. Processes might be almost revolutionized. Improvements might be made in colors and new colors added. New ef-

fects might be created in art glass. Economy might be effected in the purchase of raw materials, and new ones added to take the place of older and more expensive ones. One thing will, however, be absolutely necessary, and that is co-operation of the manufacturer with his chemist, and vice versa; they must display absolute confidence in each other. At present the superintendent of the plant is often Czar because he understands the technical side from beginning to end, having worked in the factory from boyhood. He is usually poorly educated and refuses to co-operate with the chemist, who he thinks should confine himself to analytical work. If the superintendent is not in sympathy with the chemist's proceedings, and complaint is made to the manufacturer, the chemist is usually sacrificed.

One very important point which the manufacturer should bear in mind is that he cannot forever retain his chemist at a low salary. If the chemist is instrumental in reducing the cost of materials or manufacture, why should he not be given some consideration? This might be accomplished either by an increase in salary, or by leaving his salary stationary and offering a percentage of the profits as an inducement for further investigation along economic lines of manufacture. A good chemist who is properly appreciated in a manufacturing establishment is as valuable an asset as the manufacturer can acquire, and as long as given proper treatment the manufacturer need have no fear of losing any of his trade or manufacturing secrets. He takes a far greater risk in constantly changing chemists. The manufacturer should remember that the chemistry and principles of glass manufacture are meagerly dealt with in the great majority of universities, and that he has to reinstruct almost every new chemist he employs.

The writer's plea, therefore, is that the glass manufacturer employ a chemist and co-operate with him. Doing this, he can rest assured that in most cases he will be the one to profit.

DISCUSSION.

Mr. Frink: In regard to silvering glass. You said you had spotted mirrors for a time. That has been one of the greatest bug-bears to the mirror people. I would like to know what has been found to be the cause of that.

Mr. Silverman: The cause in this case was the presence of grease in the distilled water from the power plant, and as soon as that was eliminated we had no difficulty.

Of course, you occasionally meet reflectors, that is, the unsilvered article, which have been lying around the plant for a number of months, where dust and dirt get into them, and there, of course, you necessarily have spotting if there is anything there which tends to oxidize your silver. But the oxidation in our own case was chiefly that due to the presence of grease.

Mr. Frink: Did you ever find that the ingredients, the components in your glass, or the melting conditions, would ever affect your mirrors?

Mr. Silverman: The condition of the glass itself?

Mr. Frink: Yes, the melting conditions under which it is made.

Mr. Silverman: I never noticed anything of the kind. I might say that the difficulties experienced with grease and oil in the water from the power plant were overcome by allowing the water to remain in tanks for a short length of time, when the grease would float to the surface, could be skimmed off, and the water employed for rinsing reflectors rather than specially distilled water, which would have entailed additional expense.

Mr. Frink: A year or so ago I was connected with a concern which made considerable glass for mirrors, and in making this at one time they got a "teaser" from the old country who laid his own batch, and in doing so he got into trouble, either through not understanding the furnace or through his batch in some manner, and he kept increasing his soda up to a point where he got to using about 48 pounds of salt cake to the 100 pounds of sand, and that

put his soda content in his glass approximately 15 per cent. If we silvered an old light of glass, that is, a light that had been in storage a considerable time, the mirror would look very nice when it first came out, but inside of 48 hours' time, if put in the sun, it would begin to show up spots.

Mr. Silverman: Was not that due to the excessive amount of soda?

Mr. Frink: Yes, that is what it was, or perhaps the absorption of the nitride from the soda.

Mr. Staley: I would just like to say one thing. I think it is up to the young chemist to grin and bear it and work into the good graces of the superintendent, because he is the power that is, and if you are going to hold the job and accomplish anything worth while, you have to stand in his good graces.

Mr. Silverman: I should like to ask whether the gentleman who has just spoken has been employed by a company having a series of eight or ten plants under the direction of a general superintendent? The difficulty is not so much with the local superintendent, because you are with him constantly and you and he become more or less attached to each other. But when a general superintendent is the one who has charge of the entire work, and very often carries those secrets which even the local superintendent himself does not possess, I refer now especially to batches, it is a case in which the local superintendent makes up the bulk of the raw materials, and the general superintendent comes around once a week and makes up a dish pan full of some special secret material which is added, then when something goes wrong with the glass the chemist is approached, and he is the one who is supposed to tell just exactly where the trouble is. He is supposed to explain it off hand. Can a young chemist do anything of that kind? At the best he can say, I don't know. If he admits that, he is not supposed to be worth very much. If he tells the superintendent that he does not understand it because he does not possess the formula of the batch, he is

told that he must not ask for that so soon, as he is not yet long enough in the company's service.

So in the case mentioned, the best that could be done was to control the lime and pearl ash. The quantities of lime and pearl ash used were furnished the chemist, though proportions of other substances in the batch were not given. Daily corrections were thus made for lime and pearl ash only. Cases of this kind crop up constantly. The general superintendent, of course, can tell borax from soda ash by simply feeling it, and he can distinguish between the various substances around his plant by picking them up and seeing how they sift through his fingers, or how they seem to the touch. The young chemist is not as fortunate as that. That is the education he lacks. But there are many points coming up daily in a factory where a chemist can be of a great deal of assistance if he has the confidence of the manufacturer.

Mr. Frink: There is one subject in the glass business—fuel economy—that has not yet been touched upon, wherein I believe the chemist can save more money for the manufacturer than in any other way. We all know that the principal cost of glass making is labor and fuel. The fuel question is one that is paramount to the glass men today, and the chemist, by giving his attention to this, can save his salary every month that he is on the job. I have seen this demonstrated time and time again.

Mr. Takahashi: I agree with Professor Silverman and Mr. Frink in the points that the glass maker can save a considerable amount of money through work of a chemist. Just a few days ago I started an experiment, trying to reduce the cost of a batch. The batch costs about $1.00 per hundred weight, but by using some other cheaper substances in place of some ingredients that we are using and eliminating some materials, such as borax, antimony or arsenic, which I believe are not necessary ingredients, and in many cases are just put in because some one tried them and got a good result, (or possibly no harm, but did not know whether it was due to these substances or not, the

chances being that it was not) we can make about the same grade of glass for less than 50 cents per hundred weight. I know of one instance where nitre was eliminated and soda was increased just a little, and the amount of saving from this change was over $1000 a year. I believe also a chemist can do a good deal in the saving of fuel.

Mr. Frink: Mr. Takahashi has struck the key note of this whole situation, the elimination of useless materials in the glass business. There is more useless waste in the glass business than in anything else on earth in the shape of a manufacturing industry. That is a broad statement, but I believe it is a fact.

Mr. Silverman: The point brought out about antimony oxide or arsenic oxide was one of the very first things that occurred to me in this line of work. As a rule, in other branches of manufacture we try to eliminate arsenic and antimony and here in the glass industry we are using considerable quantities, in fact, some glass makers by the car load. The suggestion was made to the company referred to in my paper that they eliminate arsenic and antimony, or at least permit experiments to be conducted so that they could find out whether they might be eliminated, or a cheaper substance substituted, but permission was not granted because they felt the worker would throw up his job if he ever found out that arsenic and antimony had been left out of the glass. I believe the worker has the idea that arsenic and antimony must enter into the composition. It is time these superstitions were knocked out.

Professor Orton saw the clouded glass referred to in my paper. That was originally tried from a flint batch which contained a considerable quantity of oxides of antimony and arsenic. When the flint batch was finally used for the production of the clouded glass the antimony and arsenic were omitted, and a very highly polished surface resulted. So there was a proof in actual practice where antimony was left out of the flint glass and a perfect gloss was obtained on the surface, and at the same

time there was no more reduction in lead than in any of the other cases. That the glass is still made in large quantities is additional testimony. The claim is made that the arsenic and antimony increase gloss and hardness and prevent reduction of lead. I do not believe it.

Mr. Orton: Mr. President, I think the society is indebted to Professor Silverman for coming over from the University of Pittsburgh and giving us this paper. He did so at my request, though not a member of the Society, and I think we are indebted to him for it. At the same time he has demonstrated very clearly the wisdom of my request to him that he prepare a paper on the subject of ruby glass, because on the occasion that he showed me that beautiful piece of clouded glass, he showed me some samples of work in the ruby line that I am sure would be of very great interest to this body, and if we can prevail on him, if the other members present will assist me in that, I hope that in another year from now we may have two things, one is Professor Silverman's name on our rolls, and another is a paper on Ruby Glass.

MANUFACTURE OF DUST PRESSED WARES.

BY

GEORGE SIMCOE AND ALBERT E. SMITH, Trenton, N. J.

The vital elements of dust pressing are confined to the body that is to be used, or the size and shape of the piece to be pressed.

It was our impression that neither very plastic nor very short bodies could be made by the dust process. Assuming this to be true, we made up a number of bodies to show the effect of high and low plasticity, as follows:

SERIES F.

Number	1	2	3	4	5	6	7	8	9	10	11
Florida Clay	13	11	10	9	8	7	6	5	4	3	2
Flint	2	3	4	4	4	4	5	6	7	7	8
Spar	5	6	6	7	8	9	9	9	9	10	10

A twenty pound sample was used. We blunged the samples by hand in a bucket, and after putting through a 120 mesh screen, poured in plaster moulds to dry.

After sufficient drying, we put each individual sample through our disintegrator (or blower). This gave us a good chance to see the relative grinding qualities of the eleven bodies; the data being given in a table shown later.

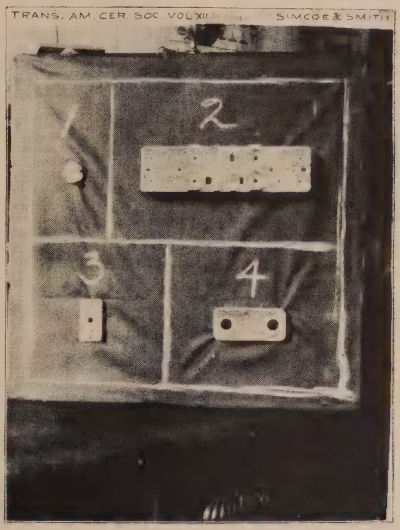
In order to have as wide a variety in size and shape expressed by our pressed samples, we adopted the following general forms:

1. Small Plain,
2. Large Plain,
3. Small Complicated,
4. Large Complicated.

As types of these general forms, we used the following electrical porcelain shapes:

1. Small Taplet,
2. Telephone Switch Base,
3. Socket Button,
4. Cut out.

Shown in Fig. 1.



The following table will show the grinding and pressing qualities of Series "F":

Number ...	1	2	3	4	5	6	7	8	9	10	11
Small Plain.	Good	Good	Good	Good	Good	Good	Good	Good	Fair	Fair	Fair
Large Plain.	"	"	"	"	"	"	"	"	"	N.G.	N.G.
Small Comp	"	"	"	"	"	"	"	N.G.	N.G.	"	"
Large Comp	"	"	"	"	"	"	"	"	"	"	"
Ground....	Bad	Bad	Bad	"	"	"	"	Good	Good	Good	Good

Contrary to expectation, we found none of the series too plastic for grinding, though several had to be put through the grinder two or three times. We did, however,

as you will note on the table, find as we decreased the plasticity of the bodies, quite a number that were apparently worthless so far as pressing qualities were concerned.

In order that we might have an impracticable body at each end of the series, we designed a new series, using as No. 1 a very plastic English ball clay, straight. The new series is as follows:

SERIES E.

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Eng. Ball	20	18	16	14	11	9	8	7	6	5	4	3	2	1
Eng. China ...	0	0	0	0	3	3	3	3	3	3	3	3	3	3
Flint	0	1	2	3	3	3	4	4	4	4	5	6	7	7
Spar	0	1	2	3	3	5	5	6	7	8	8	8	8	9

After blunging, screening and drying as in Series "F," we ground and pressed Series "E," with the following results:

Number	1–6	7–9	10, 11	12	13	14
Small Plain.....	Good	Good	Good	Good	Fair	Fair
Large Plain	"	"	"	"	N.G.	N.G.
Small Comp.....	"	"	"	Fair	"	"
Large Comp.....	"	"	"	N.G.	"	"
Ground.....	Bad	Fair	"	Good	Good	Good

When we found that there was no great difficulty in preparing body composed entirely of ball clay, we were very much surprised.

However, when we broke the fourteen different samples, we found a marked tendency on the part of the highly plastic bodies to show sort of laminations which, we believe, were due to air bubbles having been flattened out under pressure. This laminated effect diminished as the bodies got shorter, and outside of being very tender, the short bodies would seem to be the best for dust press. We found that Bourray makes this statement—"The following

quantities of water must be added to 100 parts of dry material in order to obtain bodies of equal consistency:

Pure Clay	35.5%
Half Clay, half Carbonate	27.7%
Half Clay, half Sand	19.5%

From this he deduces:

100 parts clay require	41.5 parts water
100 parts carbonate require	19.9 parts water
100 parts sand require	3.5 parts water

Our practical experience and observation would now lead us to the use of the short body, but there still remains the great fault of weakness. In seeking remedies, it was learned that many potters have for years used some sort of gum in their body, mixing it in the blunger about a quart of a starchy mass to 3,000 pounds of body. This gave good results so far as known.

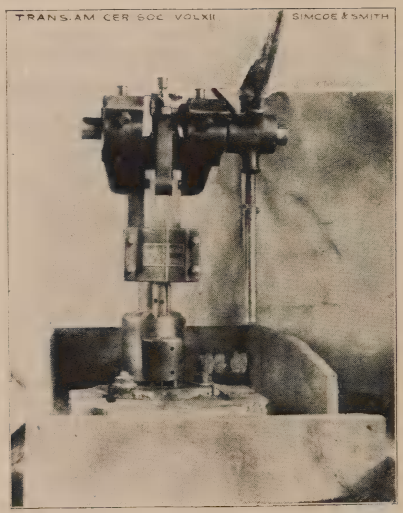
Bourray also speaks of the use of gums under the head of Agglomerative and Agglutinative Material, specifying the use of glue, gum, lichen, dextrin, soap, sugar and molasses, and for ordinary ware, tar. He further states that they use black soap and parchment glue in the soft French porcelain.

We, therefore, resolved to try a gum on such of our mixes as had proven too tender to press, and concluded to use gum tragacanth.

After several trials, we found that a mixture of 1 oz. dry gum tragacanth to 20 quarts hot water gave us about the proper solution. Much thought was given as to the proper time to add this mix to the body, but viewed from all points, we decided that it should be sprayed into the blower room as the clay is being disintegrated. For our experiments, we added the gum water to the body before it was finally screened for pressing, with good results.

With the addition of 10 cc. of the above mix to 2 pounds screened clay, we were able to press successfully all the tender bodies shown in the foregoing tables.

A slight addition of oil was then tried in order to make the clay free from the die, and in part eliminate the wear on the die from constant use of the oil brush. In this we were more than successful, finding after continued experiments that for our body a mix of 3 parts coal oil to 1 part pure lard oil gave excellent results. In fact, we are now using oil in our body for making small complicated pieces like Socket Buttons.



In conclusion, we found that much depends upon the way the clay is pressed to give it the desired thickness and density. For instance, the pitch of the screw in the majority of the modern presses is entirely too great for the final pressure. Theoretically, a crank gives the ideal pressure, and it is a question whether in time we may not abandon the old screw press, which is a man killer and an eternal element of error, and universally adopt the crank press of the German type. We have a small one in our factory at the present time, and we believe it is going to work out satisfactorily. Fig. 2.

We, therefore, as a result of our work, feel free to assume that there is practically no body that can not be successfully ground and pressed.

DISCUSSION.

Mr. Binns: This paper contains points of considerable importance that should be fully discussed. Mr. Simcoe has brought out certain phases that are quite new. How do they chime in with your experience?

Mr. Hastings: I would like to ask if putting back these scraps into the blunger again would not make trouble if they contained oil. You have to pass those scraps back again eventually into the blunger, do you not?

Mr. Simcoe: We do not put our scraps back into the blunger. I would say that you would have difficulty in that. It is a common experience with every plastic clay, or clay having gum in it, that you get into trouble with the filter press. But we simply wet down our scrap and put it right back into the "blower," or disintegrator, together with the other clay. That would remedy that objection.

Mr. Binns: Do you ever get it clean, that is, the scrap?

Mr. Simcoe: Moderately.

Mr. Hope: I would like to ask if any difficulty has been experienced due to the introduction of carbon in the body or gum tragacanth, or any other organic matter? Is there any difference in the color due to reduction or any trouble of any kind?

Mr. Simcoe: In answer to that I would say that I have not gone into it deep enough to give you a truthful, honest answer to that, but in the proportions we use, I do not believe it would give you any trouble.

Mr. Binns: I would like to ask Mr. Simcoe whether the press of which he speaks can be procured in this country.

Mr. Simcoe: It can be had of the Model Machine Co., Trenton, New Jersey, made by Mr. Miller.

Mr. Binns: I would like to ask Mr. Simcoe in this connection to tell us just how the oil or tar is introduced into the clay.

Mr. Simcoe: We mix up a certain quantity, for instance, ten cubic centimeters, more or less, whatever we would use, and we apply it with a brush, dipping a brush into the oil and sprinkling it over after the first screening, allowing it to go through the screen again after the oil is applied.

Mr. Binns: That is as I understood it. You first of all filter this clay and dry it and break it up?

Mr. Simcoe: Yes sir.

Mr. Binns: And after that you screen it through an eight to ten mesh sieve?

Mr. Simcoe: About a six mesh screen.

Mr. Binns: And then upon that mass you sprinkle the oil?

Mr. Simcoe: Yes sir.

Mr. Binns: Then what do you do?

Mr. Simcoe: Put it through the screen again.

Mr. Binns: How do you reduce it to go through the screen?

Mr. Simcoe: We do not put it through a finer mesh. It is very fine to start with. It has been blown and gone through the process of disintegration.

Mr. Binns: You put it through a six mesh and sprinkle the oil upon it, but it is not in a fine powder then?

Mr. Simcoe: It is never in a real fine powder.

Mr. Binns: You break up these filter press cakes into small pieces, small enough to go through a six mesh sieve?

Mr. Simcoe: No, we break it up. The practice is to take it from the dry room where the press cakes can be cut into fourths and piled four high and they are thrown out on the floor and that partially breaks them, and we have a man who cuts with the point of his shovel into pieces the size of, say, three inches by two inches by one

inch, something like that, small enough to put through the blower. After the clay has been disintegrated and put through a screen to get out the big lumps, then the oil is applied and the clay is put through the screen again.

Mr. Binns: Oil sprinkled over the powdered clay and then put through the screen again?

Mr. Simcoe: Yes, to get it more intimately mixed.

Mr. Binns: You do not find that the oil causes lumps of clay to form?

Mr. Simcoe: No, indeed, none at all.

Mr. Staley: I have had some experience in the foundry business with cast iron, and this machine Mr. Simcoe has been talking about is very similar to machines used for making moulds for cast iron, on practically the same process. That is, they take sand and if it has not sufficient tenacity mix a little oil with it, as Mr. Simcoe does, and mould very large pieces. But they find that in mixing the oil with the sand, for instance, in making cores, they can save a great deal of oil by a thorough mixing, so that instead of putting it through a sieve one time as Mr. Simcoe does, they put it through five or six sieves in series, or through a mixing machine.

Mr. Sandt: Does the use of this coal oil eliminate any difficulty in freeing the ware from the dies? Because that is a trouble that frequently arises in this business. Do you have any further trouble with the pieces sticking to the dies?

Mr. Simcoe: You are always liable to have a little trouble. You cannot positively eliminate that, but it is a help.

Mr. Binns: Is it found that the use of gum tragacanth causes sticking to the die in delicate pieces? Would a clay containing gum tragacanth be inclined to stick?

Mr. Simcoe: It is rather the other way. It releases. In fact, I might add that we tried a combination of oil and gum tragacanth.

Mr. Binns: Is that not rather due to the fact that by

the use of the gum you are enabled to use a less plastic clay and, therefore, eliminate part of the sticking?

Mr. Simcoe: I would not want to go on record as making that statement.

Mr. Binns: Perhaps you are not troubled with sticking at all?

Mr. Simcoe: We are not.

Mr. Binns: Some of us are. That is the reason we are asking the questions.

Mr. Simcoe: Of course, there are conditions arising when dies become undercut, they will cause clay to stick in the cup of a cut out or something like that. That is easily traced.

Mr. Parmelee: I would like to ask Mr. Simcoe whether he has tried glue or dextrine? Gum tragacanth is rather expensive.

Mr. Simcoe: No, I have not.

Mr. Parmelee: There is also a by-product which, I believe, comes from the coke factory.

Mr. Binns: I think the question of the expense of gum tragacanth is rather exaggerated. We found by a little investigation some time ago that on buying it in the original package it was possible to get it at a price which would enable it to be used even on stone ware.

Mr. Parmelee: Have you compared it with dextrine?

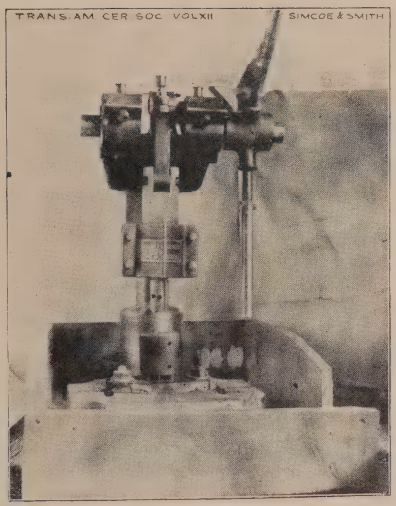
Mr. Binns: I have never used dextrine in this connection.

ADDITIONAL NOTES ON SAGGER MAKING.

BY

GEORGE SIMCOE, Trenton, N. J.

Since the presenting of certain data to the Society relative to the cost of making saggers (Vol. XI, Trans. A. C. S.), we have had practically all saggers made by a hand screw press, using two general shapes, one rectangular (11″ x 16″ outside) and the other round (13″ diameter



outside). To make these we have two dies, which are furnished with rings for varying the height of side from 2″ to 10″. We can verify the data given by Stover and Barringer in part. Having the clay cut to size and piled convenient to sagger press, three men at 15c per hour make 60 saggers per hour, making the cost per sagger ¾ of a cent. The cost of this machine was $850.00, which

included the cost of two dies and necessary rings for varying height. This appears to be an excessive price. My object in writing this note is to draw a comparison between a type of press used in Germany very extensively and the common type of screw press. We have on trial in our factory a small form of the German press used in making small porcelain pieces.

The advantages of the German press over the old screw press are as follows:

1. Better leverage (vertical instead of horizontal).
2. No screw to wear.
3. Minimizes friction.
4. Applying the fast pressure at the first stage of pressing and the slow powerful pressing at the last.
5. Eliminating one man in the operation of the press.
6. Uniformity of size of product.

We are making small ware on our press, but the principle of the pressing mechanism is much better than the screw, and I believe that a great stride in sagger-press construction could be accomplished by substituting the crank shaft or toggle levers for the screw.

SOME PROBLEMS IN CERAMIC EDUCATION.

BY

R. G. Cowan, Cleveland, Ohio.

I shall attempt to introduce for discussion several questions in ceramic education that seem to me at this time to be of importance.

The theory of education in all branches of knowledge has constantly been undergoing change and development. In general, the changes of the past few years may be stated to have consisted of a pretty complete desertion of the old ideal of education for cultural development only, and an acceptation of the very modern ideal of education for utility. It is probable that one extreme is as bad as the other, and that here as in all other branches of human thought, a middle ground is the safest. However, the new ideal of utility has affected to a greater or less extent almost all of our colleges and secondary schools. Our colleges are everywhere making their courses more practical. Even in our high schools the idea is gaining ground that the 98% of pupils who do not go to college are of as much value to the community as the 2% of the pupils who do, and the 98% are in consequence having their problems studied as never before, with practical results that are everywhere manifest. While I do not believe that the 2% should be neglected,—for it is from their number that we recruit many of our great thinkers and great men—still it is the problem of the workers in which I am most interested, and it is of this problem that I shall speak today.

The change in the theory of education which I have mentioned is in all probability due to the change in our idea of culture. The culture of the past was largely concerned with the dead,—dead languages, dead literatures,

dead arts. A thing was of educational and artistic importance in direct ratio to the distance of its withdrawal from the present. It was only in the minds of wise men, —and education and wisdom are by no means synonomous, —that a welcome could be obtained for problems of present day importance. Now all this is changed. Today we believe culture to consist of thorough knowledge, sane judgment, and keen appreciation of and delight in everything good, whether it be old or new; and that study a cultural study which will in any way make of the student a better student.

The outward and visible sign of our changed ideas and ideals is to be found in the vocational school, and the vocational school itself takes several forms, of which are the Trade School and the Technical School. The Trade School, as its name implies, seeks only to teach a trade, and like any other highly specialized means of education, is objectionable, because of the one-sided development which it produces. In our present state of industrial development, these schools may be necessary, but if so, they are a necessary evil. In the Technical School, on the other hand, the pupil is given a very general but at the same time, thorough manual education, supplemented by academic education as complete as the limitations of time will permit. All studies are selected for their usefulness. If a study cannot be put to present use, it is practically valueless, for it will not be remembered. We all remember that this was not the case even a few years ago; subjects were still taught for their value in training the mind, which had no other value whatsoever. Latin is probably a familiar,—an unpleasantly familiar—example of these studies. I presume there is no doubt that these studies did really train the mind, but why cannot the same training be secured from subjects useful to industrial and commercial workers. Even in teaching of subjects valuable in themselves, there has been in the past much that was valueless in method and useless in substance. The study

of mathematics furnishes many excellent illustrations. In this study as pursued in the past we find many subjects valueless in themselves and useless as preparation for the higher branches of the study, little eddies in the stream of mathematics, we may say. Now these are rigorously excluded at the present time from the study of the subject. In certain high schools today the course in mathematics is laid out first for the boy who expects to step from the school to the workshop, and second, practical and theoretical mathematics as a preparation for the higher work of the college, for the privileged boy who can go to college. In both cases the work in mathematics is correlated with every other subject wherever possible or practicable, and every other subject is correlated with it. In fact, we might say in general of present day education that correlation is the keynote, the beginning and the end of method. It is by correlation, by the emphasizing of the relations of each subject to every other, that we fashion those numberless hooks, more tenacious and more durable than iron, which fasten their theories and their facts forever in our memories. Is not this a better system than the old one, which allowed the boy to do his own correlating for himself in the workshop after his school days were over and done with?

It is in Germany that the vocational school has received its highest development. What her vocational schools have done for Germany industrially I need not speak of here, for we are all familiar,—perhaps enviously familiar—with. These schools are so many and so varied that it is possible for any German lad to obtain instruction in any branch of industry, and to carry on his studies to almost any extent. Many of these schools are trade schools pure and simple, whose purpose is the turning out of expert workmen. In addition to these are the technical, industrial and scientific schools, where any practical study may be pursued to almost any length in any of its branches. These latter schools are turning out the experimentors,

investigators, inventors, and executives who have made German industry and trade what it is today.

Now you are probably asking yourselves what has all this to do with the ceramic industries. My reply is that ceramic education has been undergoing the same evolution that we find in these other branches of education, only with this unfortunate difference, that it has evolved neither as fast nor as far as is desirable and even necessary for the growth and development of the ceramic industry.

The ceramic student of the past found it necessary to carry on his studies in one of two or three institutions in this country, whose courses of study, while excellent in every way, could scarcely be called practical. For his practical knowledge he depended on experience in one of our factories. The apprenticeship system, however, is a thing of the past everywhere but in our potteries, and this too for reasons logically attendant on present industrial conditions. In this way, the old practical education of apprenticeship in several of our ceramic industries has been the only education of the working man and, with the new conditions that are coming, it is insufficient, largely because apprenticeship is a relic of the past and because there are more modern methods. And as yet we have nothing to take its place. Our schools should supply this lack, but as yet they have not supplied it. Unless they do supply it there will soon be a lack of skilled workmen in the ceramic industries. They will not supply it unless there is an urgent and concerted demand from the ceramic industries of this country. Here we have a great educational need, and here we find the connection between the ceramic industries and the educational development of this country.

For example: In the whiteware business there is today a very great lack of expert workmen and foremen. Where are we to find these men? It is not hard to find boys and men willing to learn the business. Any position which pays good wages will attract workmen. But be they ever

so willing, where are they to learn the business? In the shops there is no good chance to learn even the different parts of one trade. To secure a capable foreman of clay shop or decorating shop is difficult, and there is some doubt of the capability of some of the "capable" ones. Since the industry cannot meet its own needs, it is the duty of the schools to supply the lack.

To return to the main question of ceramic education, I believe that ceramic education must be greatly enlarged and extended. In the past only scientific or engineering ceramics has been taken up in our schools with any degree of thoroughness. In the future I believe that the art side and the trade side of ceramics—the other two great phases of the subject,—must receive equal attention with its scientific side in ceramic education. I even believe it will be found to be a practical necessity to subdivide these departments into a number of others. It is of course evident that an education in any one of these lines will necessitate taking up the others in a greater or less degree.

As I have said, in the past our schools have taught only scientific ceramics. The amount of practical work given in the various schools varies somewhat, but in none is it sufficient to allow the student to take a job as foreman on leaving college. In some of these schools, also, art work is given, but this is not sufficient in extent to be called an art training, nor thorough enough to be of practical use in the successful solving of business problems. Now this must be changed, and the change must be brought about, it seems to me, by specialization. It will be necessary to divide ceramic education in the way I have indicated, and to make the course in each division stiff enough so that its graduates are certain to be efficient. The attempt to give a course that will fit the student for any position, from clay geologist to art potter, whiteware man, or brick maker, is neither just to the industries represented nor to the men themselves.

Now, the investigator is just as important as the prac-

tical man, but we do not need as many of him. This is evident when we stop to think that one investigator of genius can supply results that will keep all of our practical men busy in applying them. The time is near when the up-to-date manufacturer will not have to be an investigator into the fields of the unknown. I do not mean to say by that, that we now know all that we shall ever know about clay and glaze, but I do mean that we shall soon have a fund of knowledge in regard to these subjects large enough to suffice our potters in the manufacture of ordinary wares. Our greatest need then is not for new material, but for some one who can apply the information we now have, as well as that which will be added in the future by investigators trained for the purpose. At present the ordinary factory cannot afford an investigator. The manager must look after the executive end of the business and also do the investigating. This is neither fair to the manager nor the factory. The investigator can produce the best results only when he can give his undivided time to his work. The same is true of the executive, only that the executive must have in addition sufficient scientific knowledge of his subject to understand the results of the labors of the investigator, as set forth in our ceramic literature, and to apply it practically in the factory. Both these men are today equally essential to the ceramic industries.

I have said that these men are equally essential to our industries, but that we need more executives, more practical men than trained investigators. Naturally we shall expect to find this requirement recognized in our industrial education. But I fear our expectations are at the present time doomed to disappointment. In our ceramic education today only the scientific phase is emphasized. The practical work done in the last two years of our college courses is not thorough enough to be of much value except in giving a rather hazy idea of the methods of production. Now we cannot change this and retain our present ideal of giving the student a smattering of everything ceramic. If

sufficient time were spent on the practical to give the student a good working knowledge of the business, it would then be impossible to prepare him in the four years for extensive investigation. You see our necessities must inevitably force us into specialization.

Now we shall find it impossible to recruit our foremen from the ranks of college graduates, when these men have found it necessary to spend a number of supplementary years in the shops in order to get their practical knowledge. Men who spend that amount of time in preparation for their life work demand more money than most of us can afford to pay our foremen. Other industries offer them much greater opportunities in return for an equal amount of preparation. Yet we require educated foremen in our business. Should we not see to it that our capable young men may get the necessary practical education at a minimum outlay of time and money? The answer to this question spells something like Trade School.

The whiteware industry perhaps feels the need of the trade school more than any other branch of ceramic work. There is no other industry of any kind in this country so built up out of numberless details, in which more chemical actions and reactions take place in the course of production, and which requires such expert and varied workmanship. And in addition, in this industry the sale of the product depends on its artistic worth in the eyes of the buying public, whose taste is constantly becoming more exact and discriminating. Here we have a natural combination of the three divisions of ceramics previously mentioned. The scientific, the executive and the artistic. And yet we have been expecting and attempting to educate our young men for this sort of work, by four years of preparation in the scientific branch. Now we are certainly getting some real results from scientific investigations, as I have said, but until the executive and the artistic phases are given their place, and the attention they deserve in our education, there will be no complete rounding out of the

results of our scientific investigations. Only when all three are working together will any adequate degree of efficiency be obtained from the work of any one of them, and only then will ceramics as a whole approach its ultimate goal.

To return to our present system of education. Let us grant that the college student of today is willing to spend the necessary years in the shops after graduation to obtain his practical experience. Now arises the question, will he get the chance? I am not going to discuss here the desirability of unions. In this case, however, the unions do work a hardship. They insist on a certain ratio of apprentices of one or two years is discouraging to the student, especially when, as, in the case of the presser's trade, the first year is spent in making soap slabs. Now it has been found that two years in a trade school give a broader and more thorough training than a four years' apprenticeship, not only in theoretical knowledge, but in manual skill and deftness. This is not difficult to understand when we consider that the student is pushed on as rapidly as possible while the apprentice is not, and that the student is taught his work in a systematic manner and with a certainty of method, with which the slipshod methods of the apprenticeship system cannot even begin to compare. To prepare a man for a position as foreman would require even less time than would be spent on the ordinary worker, for in this case it is the knowledge of what to do and how to do it that is essential, while the deftness that comes only from practice is not. Perhaps it might be best to have such a trade school offer two courses, one of two years and one of four years, the two year course being purely a trade course, and the four year course giving in addition some training in the other related trades and their underlying principles, together with such desirable subjects as mathematics and English. Such a school would occupy a place in our country's educational system on a level with the high school, except that everyone should be admitted who desired the work, and who gives promise of being a good workman

after completing his course. Thus anyone finishing the four year course would be able to go to work at the trade, and at any time to take the position of foreman. Of course these trade schools should be established only in the localities where ceramic industries are situated.

There is, however, another type of secondary school of recent origin in this country, which is bound to exercise a great influence on the future of ceramic work, and of this type the Technical High School of Cleveland is one of the best examples. In this school the art side of ceramic work is being taken up more seriously than in any other school with which I am acquainted. Here indeed the work is attacked almost entirely from the art standpoint, only enough emphasis being laid on the scientific phase to make intelligent effort possible. The presence of ceramic work in this school and the manner in which it is taught are both results of what is often called the Craft Movement in this country.

The school, speaking in general, has a two-fold policy. First, to prepare for their life work those pupils who can not or will not go to college. Second, to prepare pupils in a more practical and thorough going manner than that usually attempted for our scientific and engineering schools of college grade. The courses in all subjects are specialized and arranged in accord with the modern ideas mentioned earlier in this paper. All subjects are correlated in the most practical and helpful manner, and there is nothing in the course which does not make for efficiency, although the general education of the pupil is not lost sight of. Indeed I am heretic enough to believe that the general education these people receive is far superior to that obtained in the older or academic or classic high schools. Here we find practically every subject of study focussed on the problem the pupil has before him in the shop. In fact, the shop is only a means for giving visible shape in wood or metal or leather or clay to the ideas conceived and worked out in the other class rooms. Every

course is worked out with the idea of developing a creative mind and at the same time of teaching the hands to obey that mind. This school may be said to be the pioneer school of this kind in the country, and it is now only in the second year of its work, four cities, at least, having since started such schools and Cleveland just breaking ground for a second Technical High School. Already its graduates are admitted without examination to the engineering and scientific departments of Case School of Applied Science, and of Cornell University,—a high proof of the excellence both of its course and its instruction.

Now in the ceramic department of this school this same idea of the development of the creative mind and the trained hand is carried out. Here the pupil, with the aid of the teacher, creates, forms and designs for ornament, and then carries out his designs in the clay. Indeed it has been learned that clay is probably the best medium for the expression of applied art. It lends itself to almost any grade of work, from that of the youngest child to that of the greatest artist. It has everywhere been found to be of such value that in all art schools it is a part of the required work for all pupils. In the Technical High School this required work is for but one term of the first year. In the second year of the art course the time is practically all given to design. In the third and fourth years the pupil is allowed to specialize in any line of art, and many of them have already chosen Ceramic Art, or "Pottery," as it is called in the school.

We have been criticised for giving such courses to young pupils, who are unable to realize the large part that the firing and the glaze have in any piece of work. As there are always two sides to every question, we must recognize that there is some truth in this argument. The truth of the matter, as I shall try to show, is that the design of the form and the design of the ornament, including the selection of the glaze, is really of as great importance as

the glaze itself. Far too much emphasis has been laid on the scientific achievement and not enough on the art.

Now, as I mentioned before, the standard of excellence of art wares still largely consists of false values given because of the rarity of the piece or its difficulty of manufacture. The time standard should consist of a valuation based on the artistic worth of the piece itself and its utility, and as well the way it fits its surroundings.

The "Arts and Crafts Movement" is an attempt and a successful one as far as it has gone, to raise this true standard to the place it should occupy in the minds of the people. The men and women who have been the chief workers in this cause have brought about an appreciation of beautiful, even though cheap, materials and objects. An example of this change, aside from ceramics, can be found in the making of jewelry. Never before in the history of civilization has there been such an extensive use of semi-precious stones and stones that could hardly be called that, in the making of high-class jewelry. This is due to the fact that in the designing of jewelry the considerations are more now the beauty and artistic effect of the article itself and its artistic effect to the wearer. Last and least is considered the monetary value of the materials used. This is as it should be. In brief, these craft workers have taught us that there should be a higher value and that there is a higher value for all things than that set by a money value. They have taught us to see the beauty that lies in the common materials with which we have to do, when used in the right way. Now, in applying these principles to ceramics, we will find that a false standard has been set up. We have valued this or that vase because it cannot be duplicated, being probably a result of some accidental and unnoticed treatment in its production. Another vase is valued because it has been made at the expense of superhuman manual skill, another because the glaze recipe is a secret, and so we could go through the list showing how the value of ceramic ware has been too largely based on an

inability to duplicate, for any of several reasons. This society is doing all possible to make known to the world all the knowledge of ceramics which has heretofore been unknown, or perhaps known to a few. The time, which is coming, when there will be no secret means, and a different and better standard be raised, means that all of us will then fully realize that it is not the material that counts but the way it is used. Then we will give to the study of how to apply materials the importance such study deserves.

There are two classes of students in these secondary schools who take these pottery courses. The larger number are those interested in applied art as a whole. To these the pottery course is largely cultural. The other class of students is the smaller, consisting of those intending to make direct use of their knowledge either as teachers or commercial workers. From the first class or those deriving most of their benefit in a cultural way, the ceramic industry in most of its branches will be greatly affected. They will be effected because these people will influence the taste of the public in as large a degree as the others. This cultural work must be recognized as a moving force in the development of ceramic art. It should not only be recognized but should be taken by the manufacturers as an index of what the better class of the public desire if they can but get it.

Now, in visiting the college ceramic schools where the scientific phase only is taught, I have been greatly impressed by the great amount of material that has been developed and the seeming lack of how to use it; in many cases there was no appreciatnon of the qualities of glazes and bodies it was most desirable to develop. Of course this is not to be greatly wondered at when we consider that they make no attempt to teach the art phase. My contention is that there can be no real development of ceramic work in general unless in the school, teaching the scientific and technical, there is enough art sentiment of

the right kind to keep the scientific development in the proper channels. It is after a visit to such a school that one fully appreciates how futile it is to try to develop one phase without the others, and how important the study of ceramic art is to all. In these two kinds of schools we have as nearly opposite types of study as possible. In the secondary technical school the work in ceramics is practically all art and the training of the hands. It would be impossible to go much beyond this with that age of students. In the case of the college ceramic students, they have had no art training and have no time for any in the present courses. Now my argument may have been in favor of greater specialization but this is so only in part, for where can be imagined a more narrow specialization than that which takes up only a broad scientific study and ignores the other aspects of the subject.

That the applied work in ceramics in the secondary school is of use to these students is very evident to those acquainted with the actual conditions. They enter such a course not knowing that bricks are made of clay and that they have to be burned. They have no idea of glazes and what they are and what for. When they finish even the short course they have some idea of the possibilities of clay and its limitations. They begin to realize what an important part it plays in every day life and, as they are interested in it as a material, ceramic objects they meet are noticed and remembered, forming that fund of knowledge out of which later their intuitions and inspirations are to be drawn.

As mentioned before, one of the greatest elements of vocational education is an insistance on an early and intimate association with both materials and methods, and it is in this gathering of information and ideas that one of the greatest benefits is derived from this element; for, the student who in early years has even a slight knowledge of the material to be used in his life work will gather a wealth

of information about his work that will in time be invaluable.

The writer used to ponder over the question of whether it was best to get the practical experience before going to college or to go to college and then get the practical experience. In either case one would get almost twice as much out of the work that followed. But how much more logical it is to follow the modern idea of the subject and give the theory and the practice at the same time and have them well correlated. The great difficulty is, as mentioned before, that in the present ceramic course there is not room for the practical, but if the modern idea is carried out in practice, two things will happen. First, the courses will be remodeled and all that is not to the benefit of the student to remember in after years, or has no bearing on what is to follow, will be cut out. Second, the specialization will be brought down so that if wanted it can be had as low as the third year in high schools. This does not apply to those who wish to follow the almost purely scientific course, but to those wishing either the art or the trade or the technical courses fitting men for industrial work.

There is no other business under the sun that requires this specialization more than does the whiteware business. It must have it and will in time, but let us hope that time will be soon.

The part that the secondary school is to take in the education of the engineering or scientific student is quite another matter, and while there is no doubt that the graduates of the technical school in the regular preparatory course will be much better fitted for the continuation of such work, there is still some question as to whether it will be possible to give them anything in ceramics.

If the ideas in this paper were followed the ceramic education of the country would be specialized into its three natural phases, with schools of three types:

1. The secondary or trade school in the trade center.

Here the important purpose would be to turn out expert workmen. This to be the two year course. Next to have a technical course of four years where the theory will be taught with the practice, and prepare students that wish it for more advanced work in college in either the trade or art phase of the work, or to go at a trade until the chance of foreman is given.

2. The secondary school not necessarily in the trade center. The important work and perhaps the only work would here be the art phase. The usual fact of an excellent art department and the facilities of the large city would give it a great advantage in this line over the school in the smaller city.

3. The college of ceramics. Here the three phases would be taken up in the art, technical and scientific or engineering courses. These would be continuations of the courses followed in the secondary schools.

I give these suggestions, hoping they may be worthy of your consideration and desiring that a discussion may follow that will hedp bring about the establishment of the necessary schools or departments.

DISCUSSION.

Mr. Stover: I think a great many ideal conditions have been set forth, and I would like to live to see a great many of them brought about. We started in Trenton with a School of Industrial Arts about the time the American Ceramic Society was organized, and I happened to be a charter member of the Institution. That school was principally for young men who were working in the day time and wanted a chance to better their conditions, and we have at last got to the point that our city recognizes that we are doing a good work and Mr. Henry C. Kelsey has put up $100,000 to make us a good building, and we hope if you meet with us in the near future to show you a completed building for work very much along this line. We

do not confine ourselves exclusively to ceramics. When you speak of 98 per cent going to high schools and two per cent going to colleges, if that is right, what we are after is the big percentage that never get to the high schools even. There are a lot of people put to work just as soon as they are able to work, and right down to the limit of the law, if not before, and there is a good deal of good material right in that crowd of boys for our foremen—in fact, many of these are our foremen today. As a word of encouragement along that line, several of our shops in Trenton have adopted a plan that any boy starting in their shops to learn any particular branch of the business that is taught in that school, has to register and show a good attendance two nights each week. Thus he may not only learn in actual practice the trade he wants to get, but he can be taught along the theoretical line of the school at night. And I tell you I have believed ever since we started our School of Industrial Arts, nearly twelve years ago, that it is a move in the right direction, and one that will bring good material from the lower ranks as well as the upper.

Mr. Cowan: I think a mistake that is being made in these schools is that they are not being supported by the city. They should be. They are every bit as important, if not more so, than the academic high school. That is what the technical high school in Cleveland is trying to do, is to reach those who think they cannot go to the high school because they have to go to work. If it is recognized that the city should support the classical or academic high school, it is ten times more necessary that the city should support the city's trade schools and technical schools that are going to turn out their industrial workers. And it seems to me that the influential members from East Liverpool and the other trade centers ought to be able to arouse the city to the fact that those schools are part of the city school system. That is being done in St. Louis, in Chicago, in Cleveland, in Buffalo and in other big cities. It is being done in the big cities and should be done in all the cities.

Dean Wadsworth, (Univ. of Pittsburgh): If I may be allowed to take part in the discussion, I wish to speak in regard to some of the practical educational applications and relative to the theoretical method of education that Mr. Cowan has so pleasantly spoken of. There are two points of view, and he has suggested culture and practice. It seems that some of us are working along a somewhat different line, a compromise, which I may state in this form: Culture or brain-training depends not so much upon the subject studied, but upon how thoroughly it is studied, and that more mental discipline is obtained by studying any subject in which the student is vitally interested than in studying any subject for culture when the student has no natural aptitude for that subject and has an intense dislike for it. I believe this principle, when followed, as it is in some schools, produces a far better result than either of those two other points of view—the culture alone or the utility alone,—because this conserves and educates many men for great usefulness who otherwise would fail, and belong to the 10 to 50 per cent of students usually lost between entrance and graduation.

In the way above mentioned culture and utility are both obtained at the same time. Another principle adopted in the school which I represent is that whatever is taught theoretically shall, so far as is possible to do so, be taught practically either at the same time or later. The student has both his theoretical and his laboratory work in connection with the institution. Previously during the vacation time, and hereafter during term time, under the new rules passed in our institution, the student was and is allowed to arrange with some firm to work with it for a certain length of time. After the work is finished, he must present a thesis on the work that he has been doing while he was laboring under the direction of that firm, and he must pass a written or oral examination upon this work. He must also present a certificate from the firm showing what work he has done, its grade as far as the firm is able

to give it, and whether it has been satisfactory or not. The student is then allowed to substitute this practical work for collegiate work that he would ordinarily carry as electives during his course. In this way, a student can shorten his college course by a year, if he has the physical and mental strength, by improving his summer vacations, or after this his term time, and thus graduate in three instead of four years. This gives great assistance to the older men who are unable to spare four years.

We adopt this same principle to aid the practical man. No matter what his learning has been before, he is perfectly welcome to come to us at any time, and without examination or anything further than simply to satisfy us that he can do the work understandingly, and can profit by his stay in the school, and he is allowed to take up any work he is qualified to enter, and to stay just as long or as short a time as he pleases. He is free from all ordinary college restrictions except simply to attend to his business while in the school. Of course he is given no degree. He can be given a certificate stating that he has taken certain work, if he so desires. We do this simply to try to help men of somewhat advanced years. If it shall later prove desirable, night school work will also be provided for these practical men.

Professor Silverman: There is one point that I was hoping Dr. Wadsworth would bring out, which is that the University of Pittsburgh is working along the line that has been suggested, but in my opinion to even a more perfect degree. The plan that is before the Board of Trustees now, and I believe has been passed, although not in complete detail, is such that a man will get his full training under the supervision of the University. The entire year will be split up into four quarters, three of which the student will spend in the University and the fourth in the manufacturing establishment selected by the professor. By doing this in the freshmen, sophomore, junior and senior years, spending one-fourth of each year in local manu-

facturing establishments, he may receive graded instruction in the practical field at times when his education permits him to understand it fully. That is carrying out to perhaps an even greater degree, the plan which was suggested for the Cleveland Technical High School, and will enable us to graduate men who are ready for responsible positions.

SOME CHEMICAL AND PHYSICAL CHANGES IN CLAYS DUE TO THE INFLUENCE OF HEAT.

BY

J. M. KNOTE, Urbana, Ill.

All who have studied clays are aware that the temperature range in which chemical and physical changes may take place, extends from the ordinary atmospheric temperature up to about 1850°C, at which point even the most refractory clay is profoundly affected, both by physical and chemical reactions. The temperature intervals in which reactions of commercial importance occur have been studied with more or less thoroughness, as a survey of the literature will show. Ashley[1], in his studies of the colloidal matter in clays, worked at ordinary atmospheric temperatures. Bleininger[2] heated clays to a point considerably below the temperature of dehydration, and produced reactions of great practical importance. The dehydration of clays has been studied by numerous workers. F. W. Clark[3] and others have attempted to determine the compounds formed when dehydration occurs. Le Chatelier determined the heat changes in some clays when they were heated rapidly from atmospheric temperatures to a high heat. Purdy[4], Bleininger[5] and others have studied the physical and chemical changes produced in clays, and mixtures of clays with other substances, between cone 010 and cone 11. The formation of sillimanite at about 1350°C has been the subject of much experimentation and speculation, and finally the determination of the point of fusion of fire clays has become common.

[1] Trans. A. C. S., Vol. XI.
[2] Trans. A. C. S., Vol. XI.
[3] Bulletin 125, U. S. Geological Survey.
[4] Trans. A. C. S., Vol. IX.
[5] Trans. A. C. S., Vol. X.

It is apparent that very little attention has been paid to what takes place in a clay from the time it begins to lose its combined water until it reaches a point where the reactions of vitrification are started. And there has been no data published on the physical and chemical behavior of fire clays at temperatures above cone 11 and below their fusing point. So the object of this work is to investigate these neglected regions.

The work naturally divides itself into two parts: one an investigation of the behavior of clays below 1000°C, and the other the behavior of refractory clays above 1000°C.

PART I.

INVESTIGATION OF THE CHEMICAL AND PHYSICAL CHANGES THAT OCCUR IN CLAYS AT TEMPERATURES BELOW 1000°C.

Method of Investigation.

Above cone 010, changes in porosity and apparent specific gravity of trial pieces indicate chemical and physical changes, and have been found of great value in studying clays, but below cone 010 these methods of investigation do not apply. The true specific gravity, as determined with the pycnometer, and the chemical properties of the material, would be most likely to indicate and explain any changes which take place.

Determination of True Specific Gravity of High Grade Clays Heated to Temperatures Below 1000°C.

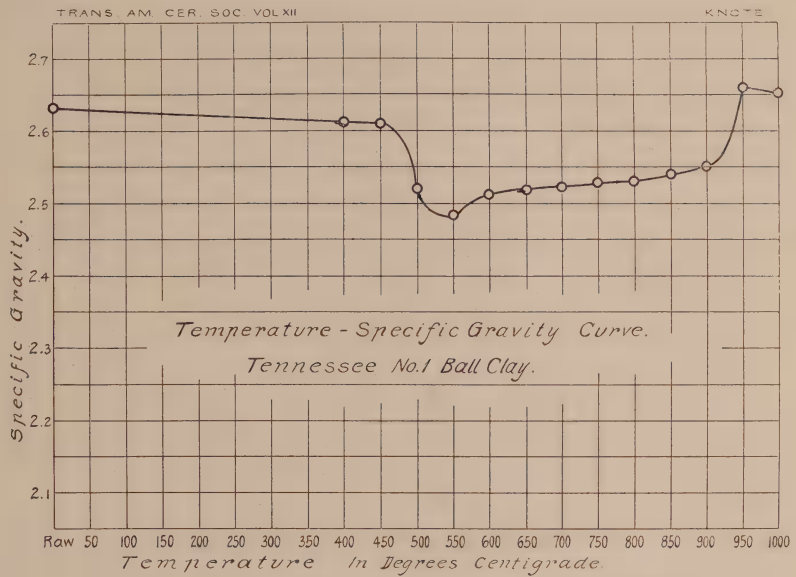
A series of the purer clays was selected to include plastic and non-plastic fire clays, ball clays, kaolins, etc. Shales and red-burning surface clays were not included, as it was desired to avoid as far as possible the effect of the ordinary diluting minerals. The clays were pulverized to pass an eighty mesh sieve. Samples were put into porcelain crucibles and these fired in the laboratory test kiln

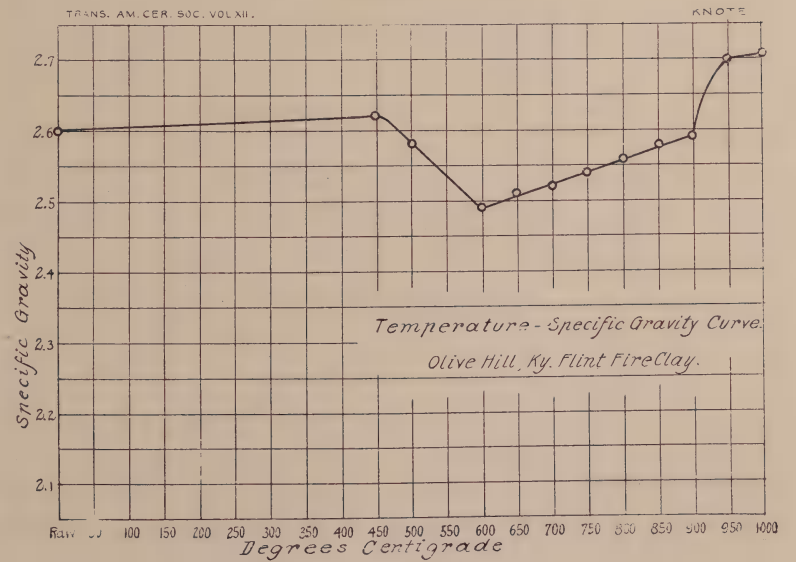
described by Purdy, Vol. IX, Trans. A. C. S. The temperatures were determined by means of a pyrometer, the end of the couple being placed as close as possible to the crucibles to be drawn. A sample of each clay was drawn at intervals of 100°C up to a temperature of 450°C, and after that, every 50°C up to 1000°C. It was not possible to burn all the clays at once, but eight burns were necessary.

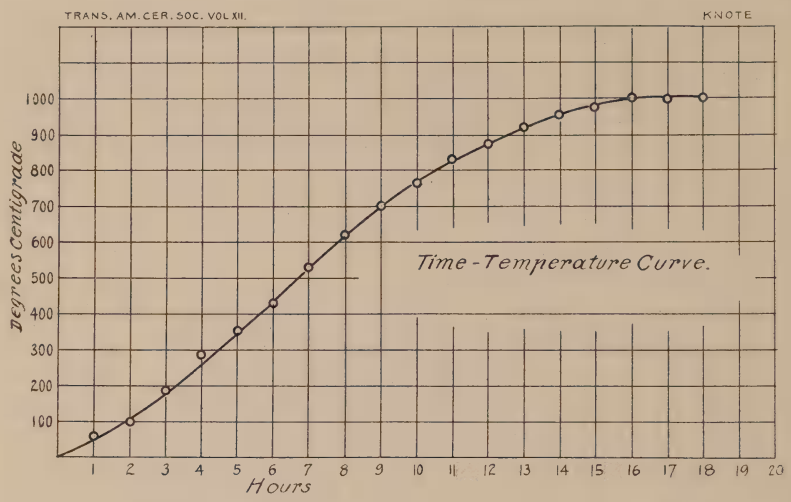
The specific gravity of these samples was determined by means of the pycnometer, or specific gravity bottle. The methods of doing this are described in various text books. Bleininger, Vol. XI, Trans. A. C. S., gives the details of the method and apparatus used in the Ceramic Laboratory of the University of Illinois. The results shown in Table No. 1, and Curves 1 and 2, were obtained by this means.

TABLE No. 1.
Pycnometer Results on Various High Grade Clays.

Temperature in Degrees Centigrade	Olive Hill, Ky. Flint Fire Clay	Olive Hill, Ky. Semi-Plastic Fire Clay	Georgia Kaolin	North Carolina Kaolin	Olive Hill, Ky. Plastic Fire Clay	Tennessee No. 1 Ball Clay	Pike's No. 2 Ball Clay	Johnson-Porter No. 9 Tennessee	Woodbridge, N. J. No. 1 Sagger Clay	Paul Clay Co., Akron, Ohio. Fire Clay	J. Poole No. 1 China Clay	Diamond Fire Clay Nelsonville, O.	"Texas Kaolin"
Raw	2.60	2.64	2.60	2.60	2.64	2.61	2.64	2.64	2.64	2.64	2.59	2.64	2.56
450	2.62	2.63	2.59	2.56	2.64	2.61	2.64	2.64	2.62	2.66	2.59	2.62	2.62
500	2.58	2.58	....	2.55	2.55	2.51	2.54	2.54	2.59	2.62	2.53	2.61	2.55
550	2.48	2.51	2.50	2.47	2.52	2.48	2.50	2.53	2.56	2.57	2.47	2.58	2.47
600	2.49	2.51	2.48	2.46	2.52	2.51	....	....	....	....	....	....	....
650	2.51	2.53	2.50	2.49	2.53	2.52	....	....	....	....	....	....	....
700	2.52	2.54	2.51	2.51	....	2.52	....	....	....	....	....	....	....
750	2.54	2.55	2.52	2.52	....	2.53	....	....	....	....	....	....	....
800	2.56	2.56	2.53	2.54	2.55	2.53	....	....	....	....	....	....	....
850	2.58	2.57	2.55	2.55	....	2.54	....	....	....	....	....	....	2.52
900	2.59	2.59	2.55	2.59	2.59	2.55	2.56	2.55	2.56	2.54	2.50	2.51	2.52
950	2.70	2.70	2.70	2.72	2.66	2.66	2.59	2.61	2.59	2.64	2.52	2.64	2.55
1000	2.70	2.70	2.69	2.72	2.63	2.65	2.66	2.66	2.66	2.69	2.61	2.64	2.57


TRANS. AM. CER. SOC. VOL XII
KNOTE
Specific Gravity.
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Temperature - Specific Gravity Curve.
Tennessee No.1 Ball Clay.
Raw 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000
Temperature In Degrees Centigrade.


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Temperature - Specific Gravity Curve.
Olive Hill, Ky. Flint Fire Clay.
100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000
Degrees Centigrade



Discussion of Pycnometer Data.

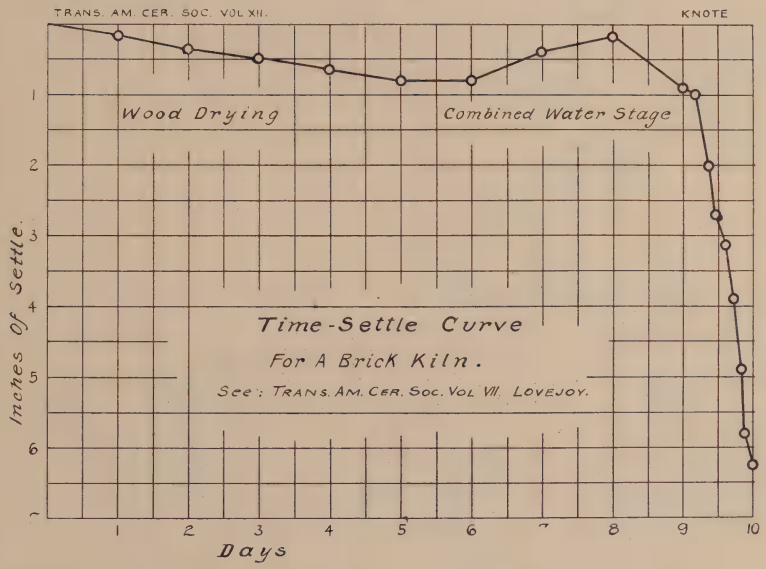
It is significant that the curves for such a large variety of clays are so similar. There may be essential differences in the behavior of various clays, but if this is true, we failed to discover it. The only difference we can see is that the non-plastic clays seem to reach a higher specific gravity at 950°—1000° C than do the plastic clays. An inspection of the results given in Part 2 of this paper will also indicate that this is true in general. The notable exceptions are in the case of Poole's No. I China Clay and the fire clay from the Diamond Clay Co. There is no doubt that the specific gravity of a burned clay is the resultant of several factors, but it seems that the physical condition is one of these.

Lovejoy's Settle Curves.

Lovejoy (Vol. VII, Trans. A. C. S.) made careful measurements of the settle in brick kilns, from the time the fires were lighted until the kiln was finished, and found that the height of the brick in the kiln increased at about the temperature of dehydration, indicating an increase in

volume of the brick. This would seem to confirm our results, as a decrease in true specific gravity would give an increased volume.

Curve No. 3 is one of the many which Mr. Lovejoy obtained.



Work to Determine the Causes of the Specific Gravity Changes Below 1000° C.

It is evident that an investigation of the chemical properties of the material is necessary to determine the character of the changes indicated by the specific gravity determinations. It has been known for a long time that weakly ignited clays when mixed with slaked lime and water are pozzuolanic in character and will set and harden. Second, it has been pointed out that dehydrated clay is much more soluble in acid than the raw material. These are the reactions which were used to investigate the character of dehydrated clay.

Clay Investigated.

It would have been desirable to investigate a series of clays, but since we could not do that a very pure plastic fire clay from Olive Hill, Ky., was used. It had about the following composition:

Silica	47.08
Alumina	39.86
Oxide of Iron	0.88
Lime	Tr.
Magnesia	Tr.
Potash	Tr.
Soda	Tr.
Loss on Ignition	12.34
Cone of Fusion	34.

This clay is described by Greaves-Walker, Trans. A. C. S., Vol. IX.

Behavior with Lime and Water.

Samples of finely pulverized clay were ignited, one to 600°C, the second to 800°C, a third to 950°C and another to 1050°C. These were mixed with 33⅓% slaked lime by grinding dry in a ball mill. The mixed material was made plastic with water and moulded into the regulation tensile test briquettes. These were kept in a damp cellar for twenty-four hours, and then immersed in water for twenty-eight days. At the end of this time, the samples which had been burned to 600°C and 800°C averaged 160 pounds per square inch, the 950°C sample 110 pounds per square inch, but the one which had been burned to 1050°C slaked down, giving zero tensile strength. This shows that the hydraulic properties are immediately lessened as a result of the change which produces the increase of specific gravity. To determine just how rapidly the clay loses its hydraulic properties a variety of clays should be tested. Our work does not show this as completely as it should, but from the work we did, a clay and lime mixture seems to behave just as a Roman cement, which is not surprising.

Behavior of Dehydrated Clay and Lime Mixtures When Subjected to High Pressure Steam.

The same mixtures which were tested for hydraulicity were put into a small steam cylinder, which was used for hardening sand-lime mixtures, and subjected to steam at 110 pounds pressure, for eight hours. The briquettes made from clay, calcined below 950°C, gave an average tensile strength of 140 pounds per square inch, and those which were heated above 950°C averaged 290 pounds per square inch. The latter briquettes were much denser and harder than those of the lower calcined material.

Effects of Chemical Reagents on Clays Calcined at Various Temperatures.

The Olive Hill plastic clay mentioned before was used for this experiment also. Three samples were used: (1) raw, (2) calcined to 600°C, (3) calcined to 1000°C. These were boiled four hours with Na_2CO_3 solution, 250 grams Na_2CO_3 per liter, with very little effect on any of them. Samples of the same material were then repeatedly boiled with 1:3 HCl solution, the residue being treated with dilute alkali solution containing 1 gram NaOH and 3 grams Na_2CO_3 per 50 c. c. (See Chemical Examination of Pozzuolane Material, Bulletin 3, Geological Survey of Ohio, Fourth Series, p. 111.)

This treatment extracted 6% from the raw clay, 44% from that calcined to 600°C, and 5% from the 1000°C sample.

This shows the very marked difference in solubility of the material calcined at different temperatures. Edgar ball clay was tried in the same way and gave about the same result, except 70% was extracted from the 600° C. sample.

Summary of Results.

(1) When the chemically combined water is expelled from a clay, compounds are formed which have a lower specific gravity than the raw clay itself.

(2) There is a sudden increase in specific gravity about 950°C, at which point Le Chatelier reported an exothermic reaction.

(3) Essentially the same curve was obtained for all clays tested.

(4) With two or three exceptions, the non-plastic clays reached slightly higher specific gravity at 950°—1000°C than the plastic clays did.

(5) Dehydrated clays which have not been heated above 900°C are pozzuolanic in character, but lose this property rapidly if heated above 950°C.

(6) Clays heated above 950°C, when mixed with lime and water and subjected to high pressure steam, give a very much stronger body than similar mixtures of clay which were heated below 950°C.

(7) Raw clays and clays heated above 950°C are not attacked appreciably by Na_2CO_3, and but slightly by HCl. Dehydrated clays heated to temperatures below 900°C are not attacked by Na_2CO_3, but are strongly attacked by HCl.

(8) The residue after treatment of the dehydrated clay with HCl is but slightly pozzuolanic in character.

Conclusions.

Our data does not show the water content of a clay in its various stages of dehydration, but we know from the work of others that the water does not all leave at once, and a part often remains until the temperature advances considerably. It would be impossible to state just what is formed as products of dehydration, without taking this fact into consideration. However, we think we have evidence to disprove the general idea that $Al_2O_3\ 2SiO_2\ 2H_2O$ breaks down into $Al_2O_3\ SiO_2 + SiO_2 + 2H_2O$. So far as we can find out, there is no positive evidence to support this view, but it is based on the fact that sillimanite ($Al_2O_3\ SiO_2$) is stable at high temperatures, while other silicates of alumina are less so. These cannot be the compounds

really formed by dehydration, as the experimental facts given above cannot be accounted for on this basis.

We wish to suggest the following as an attempt to explain the facts noted. $Al_2O_3\ 2SiO_2\ 2H_2O$ breaks up to form $Al_2O_3\ SiO_2 + Al_2O_3\ 3SiO_2 + 2H_2O$ which has a lower specific gravity than the $Al_2O_3\ 2SiO_2\ 2H_2O$.

If this change takes place in the clays examined it is fairly reasonable to assume that the same will occur in any clay, since the specific gravity changes are similar in all cases.

What causes the specific gravity to immediately increase after reaching a minimum we can not explain, unless it is the expulsion of the remaining water.

We have not proven what causes the increase of specific gravity at 950°C, but hope to have some data to offer a little later. It might be due either to the formation of an isomeric compound or to the combination of silicates to produce a new compound. Either reaction might evolve heat. We suggest a combination of the above mentioned silicates to form $Al_2O_3\ 2\ SiO_2$, but as stated before, we have not proven it. The behavior of the clay when ignited to 1000°C, mixed with lime and water and subjected to high pressure steam, is a point against the formation of an isomeric compound. Also numerous writers have spoken of $Al_2O_3\ 2SiO_2$ breaking up at high temperatures under the action of fluxes, but this statement may not be based on established facts. An acid silicate and a basic silicate are known to be formed at high temperatures, and the only question is as to what breaks up or changes when they are produced.

The fact that the non-plastic clays seem to acquire a higher specific gravity than the plastic clays is probably due to the difference in the physical condition of the clays themselves.

PART II.

This part of the investigation was devoted to a study of the physical behavior of typical fire clays in the temperature interval between cone 010 and cone 23. It was originally intended to carry every clay to its fusing point, but we were unable to do this on account of an accident to the furnace we were using.

Method of Procedure.

The nonplastic clays were pulverized to about 8 mesh and then wet-ground in a ball mill for three hours, after which all of them were plastic enough to be molded into briquettes quite readily. The charge in the mill was so adjusted that a good assortment of sizes of grains was secured, which ran 10 mesh and finer. The plastic clays were dry-ground, wet, wedged, and molded into briquettes. The briquettes were burned in a coke-fired test kiln to cone 11, a draw being taken at the temperatures indicated on the following curve sheets. For temperatures above cone 11, the oil-fired test kiln described elsewhere in this volume, was used.

Duration of the Heat Treatment.

All the briquettes were first burned in the coke-fired test kiln, the temperature being raised gradually, cone 11 being reached in 36 hours. For the temperatures above cone 11 the calcined briquettes were put in the oil-fired kiln. This was fired so as to reach 550° C. in one hour, cone 11 in two hours, cone 15 in four hours, cone 20 in five hours, and cone 23 in six hours. The burns varied from this schedule somewhat, but not enough to make any essential difference. All the clays were carried to a given temperature at the same time.

Tests After Burning.

The apparent specific gravity, porosity and shrinkage of the briquettes were obtained in the usual way. The following curves and tables show the results.

Olive Hill, Ky., Flint Fire Clay.

This clay is from the mines of the Olive Hill Fire Brick Co. at Olive Hill, Carter County, Kentucky. The clay deposits of this region have been described by Greaves-Walker, Vol. IX Trans. A. C. S. The clay at Olive Hill is at the level of the Maxville limestone, just at the top of the Sub-Carboniferous or Mississippian strata.

The following analysis is typical:

SiO_2	43.80
Al_2O_3	40.71
Fe_2O_3	0.81
CaO	0.96
MgO	0.13
Volatile matter	13.43
Cone of fusion	34-35

Under the microscope in thin sections, the clay is seen to be made up almost entirely of a structureless ground mass, which has very little effect on polarized light. Embedded in the ground mass are a very few rounded grains of quartz, and a small amount of a micaceous mineral, a few grains of rutile, zircon, etc. There are areas which represent pebbles which are now entirely decomposed to a substance differing from the material in which they lie, in consequence of their greater richness in micaceous particles.

RESULTS.

The specific gravity curve proves to be practically a straight line up to cone 23, which is a most unusual condition. Another noteworthy fact is that the clay decreases in porosity between cones 05 and 11 without any change in specific gravity. The high fire shrinkage seems to be characteristic of some flint clays, but the data which follows shows that it is not true, by any means, of all of them.

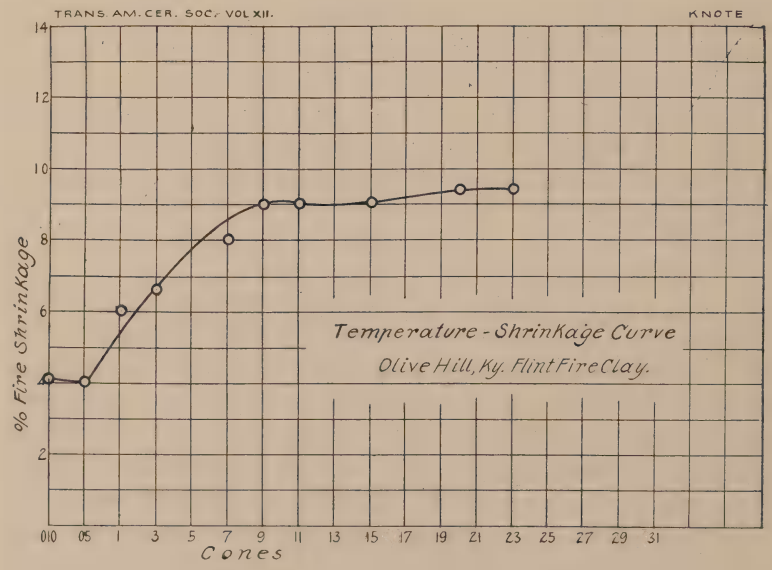
The microscopical examination failed to show any crystalline structure in this flint clay, or in any other flint clay examined. Under polarized light, the ground mass behaved as an amorphous substance.

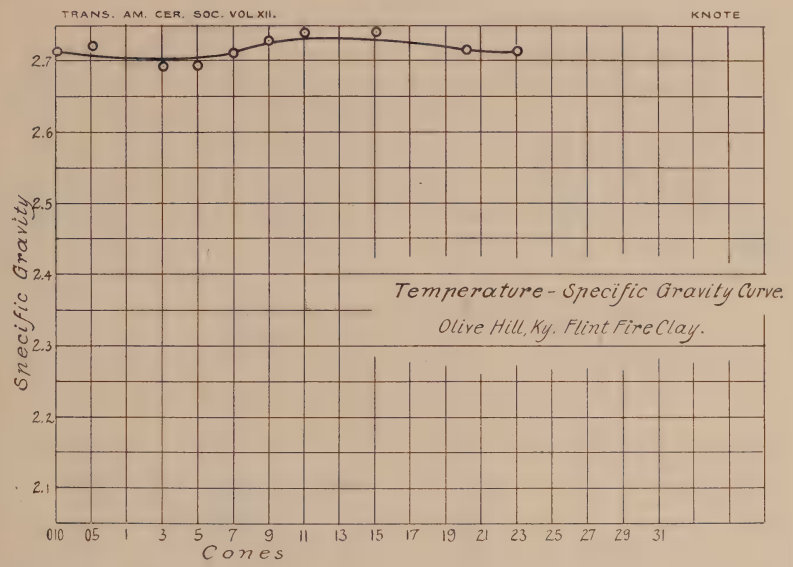
TABLE I.

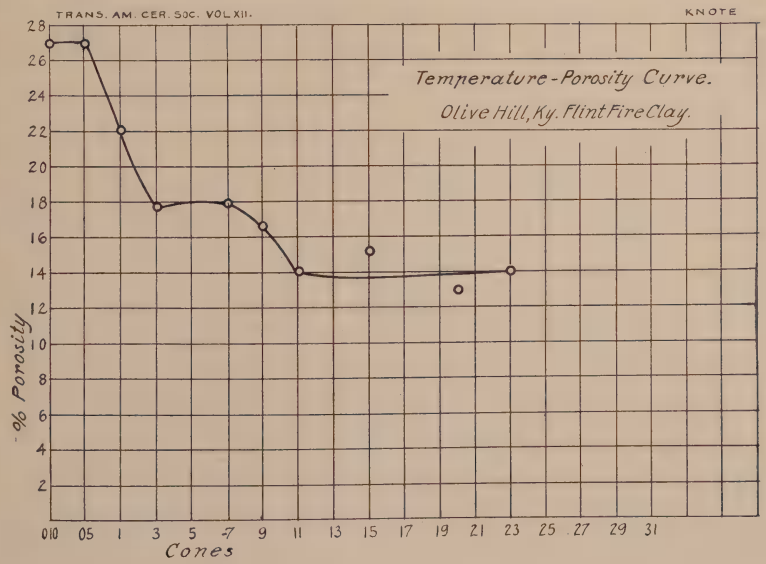
OLIVE HILL FLINT FIRE CLAY.

Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	4.0	2.71	26.4
2	05	4.0	2.72	26.4
3	1	6.0	2.69	22.0
4	3	6.5	2.69	17.8
5	5	...	....	....
6	7	8.0	2.71	18.0
7	9	9.0	2.73	16.7
8	11	9.0	2.74	14.0
9	15	9.0	2.74	16.0
10	20	9.5	2.71	13.5
11	23	9.5	2.71	14.0




TRANS. AM. CER. SOC. VOL XII.
KNOTE
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Temperature - Specific Gravity Curve.
Olive Hill, Ky. Flint Fire Clay.
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones

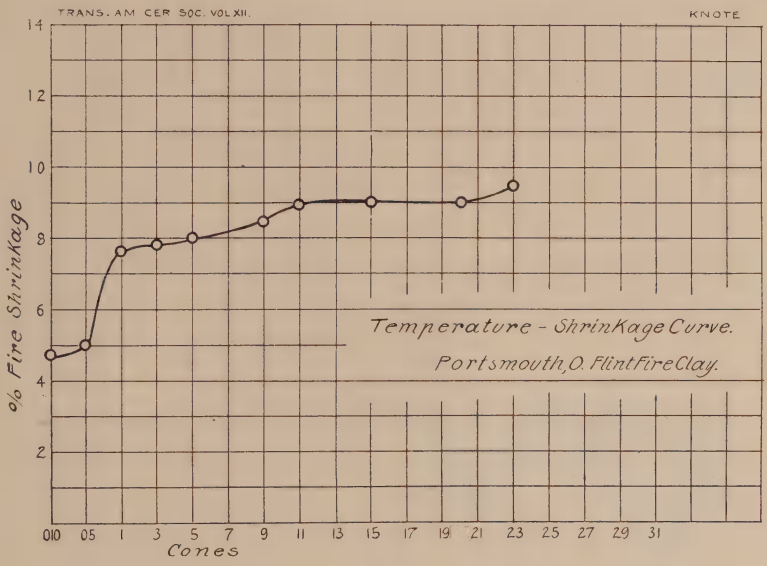

TRANS. AM. CER. SOC. VOL XII.
KNOTE
% Porosity
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Temperature - Porosity Curve.
Olive Hill, Ky. Flint Fire Clay.
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones

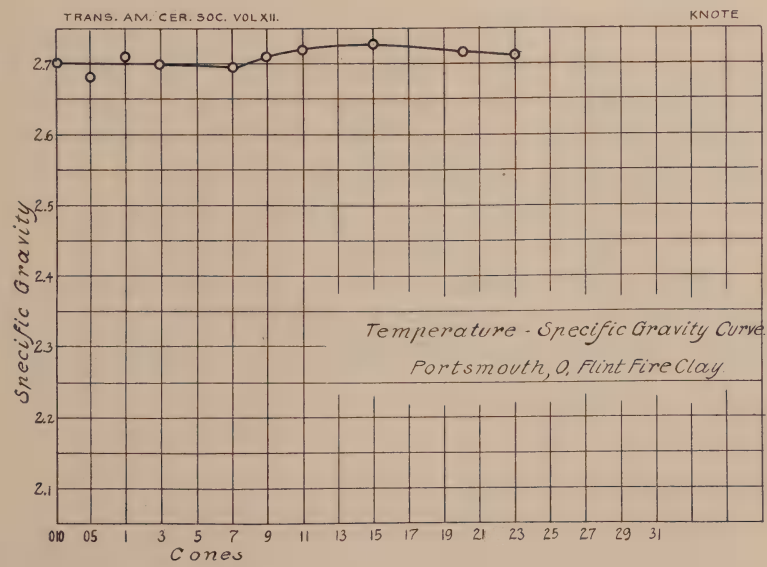
Portsmouth, O., Flint Fire Clay.

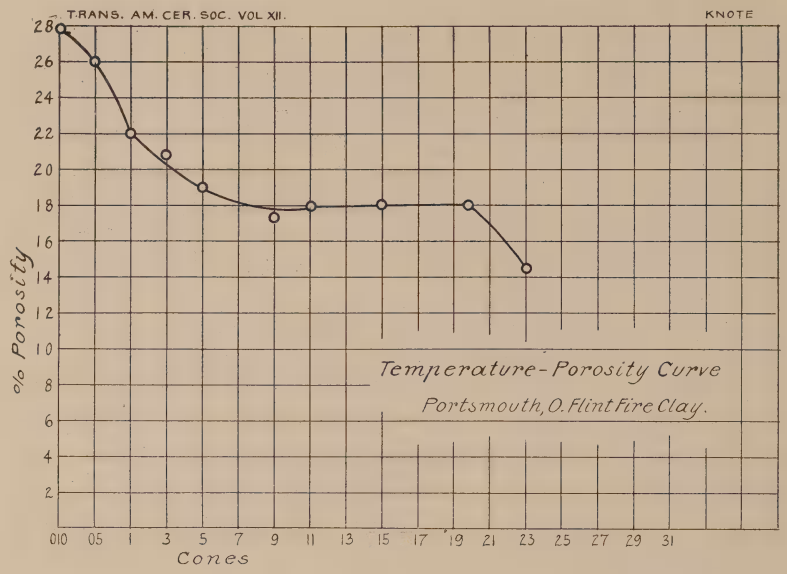
The geological horizon, occurrence, and properties of this clay are the same as those of the specimens from Olive Hill, Ky. It is rather noteworthy that, considering the great variation of the flint clays even in a restricted area, two clays from such widely separated deposits should be so nearly identical, even if they do occur at the same horizon.

PORTSMOUTH, O., FLINT FIRE CLAY.
Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	4.48	2.70	28.0
2	05	5.0	2.68	26.3
3	1	7.7	2.71	22.1
4	3	7.9	2.70	21.0
5	5	8.0	2.69	19.2
6	7	...	....	....
7	9	8.5	2.71	17.6
8	11	9.0	2.72	18.0
9	15	9.0	2.73	18.0
10	20	9.0	2.72	18.0
11	23	9.5	2.71	14.5
12	..	...	....	....


TRANS. AM CER SOC. VOL XII.
KNOTE
% Fire Shrinkage
14
12
10
8
6
4
2
Temperature - Shrinkage Curve.
Portsmouth, O. Flint Fire Clay.
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Temperature - Specific Gravity Curve.
Portsmouth, O. Flint Fire Clay.
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones



McKeesport, Pa., Flint Fire Clay.

This clay was supplied by Mr. J. P. McIntyre, of McKeesport, Pa., from a tract in Bell Township, Clearfield County, Pa. It is marked McKeesport Clay to distinguish it from another clay also from Clearfield County, Pa. Nothing is known of its exact occurrence, chemical or mineral constitution. It was rather dark in color and had the usual physical properties of a flint clay.

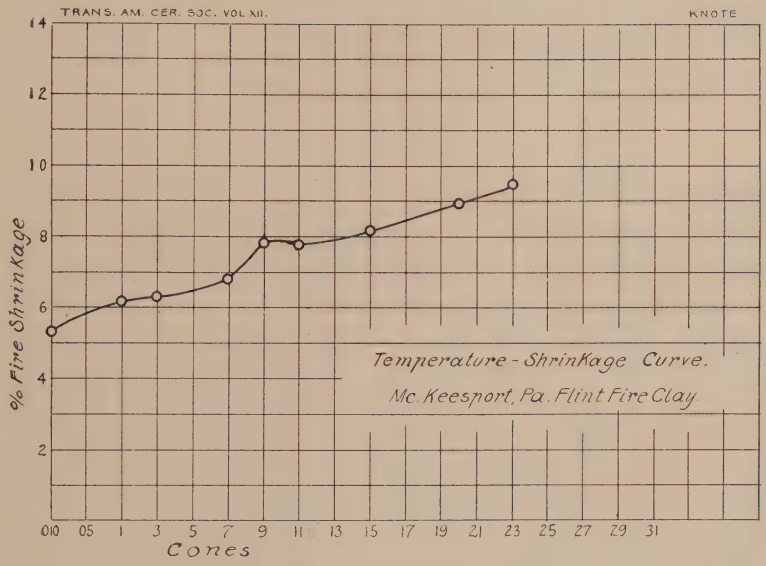
RESULTS.

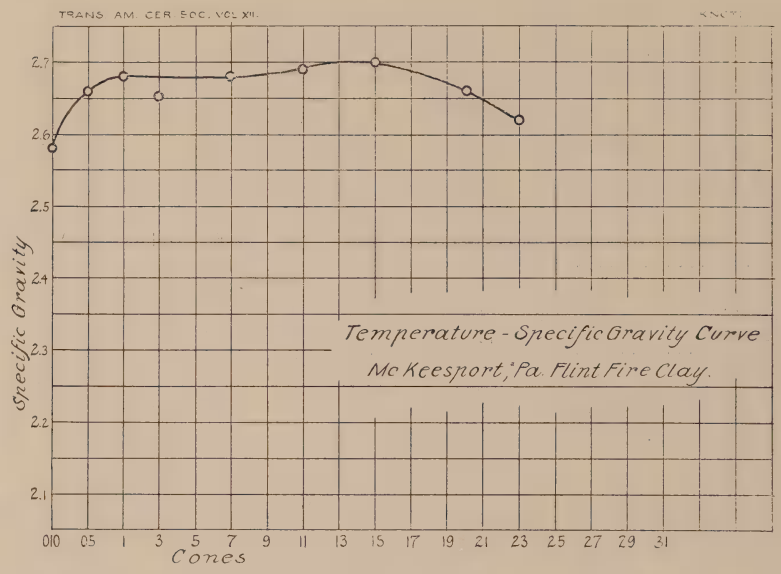
The specific gravity begins to drop about cone 15, which distinguishes it from the Olive Hill and Portsmouth clays. The porosity and shrinkage seem to change gradually but almost continuously.

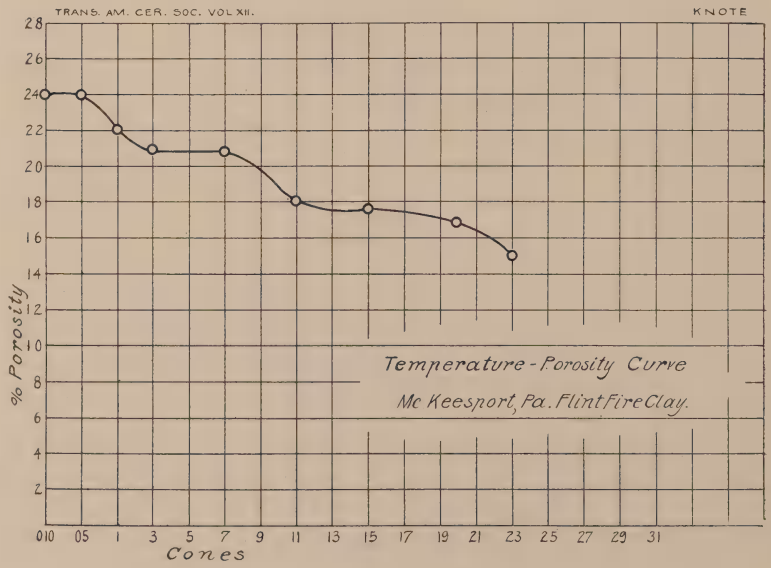
McKEESPORT, PA., FLINT FIRE CLAY.

Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed In Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	5.3	2.58	24.0
2	05	6.1	2.66	24.0
3	1	6.1	2.68	22.0
4	3	6.2	2.65	21.0
5	5	...	....	....
6	7	6.8	2.68	21.0
7	9	...	....	....
8	11	7.9	2.69	18.0
9	15	8.2	2.70	17.8
10	20	9.0	2.66	16.5
11	23	9.5	2.62	15.5




TRANS. AM. CER. SOC. VOL XII.
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Specific Gravity
Temperature - Specific Gravity Curve
Mc Keesport, Pa. Flint Fire Clay.
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones


TRANS. AM. CER. SOC. VOL XII.
KNOTE
28
26
24
22
20
18
16
14
12
10
8
6
4
2
% Porosity
Temperature - Porosity Curve
Mc Keesport, Pa. Flint Fire Clay.
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones

Clearfield County, Pa., Flint Fire Clay.

This clay is being used at the present time for the manufacture of first class refractory wares. As nearly as we can determine from survey reports, it occurs at the level of the Mercer coals in the Pottsville conglomerate. Under the microscope it shows a little more quartz than the Olive Hill clay, but the ground mass which makes up the bulk of the material seems to be the same and affects polarized light very little. The quartz grains nearly all exhibit strain as though derived from a schist.

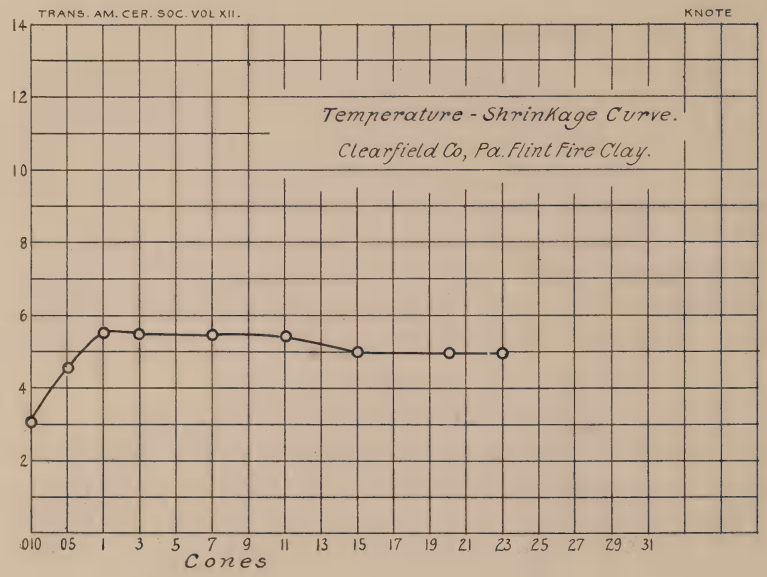
RESULTS.

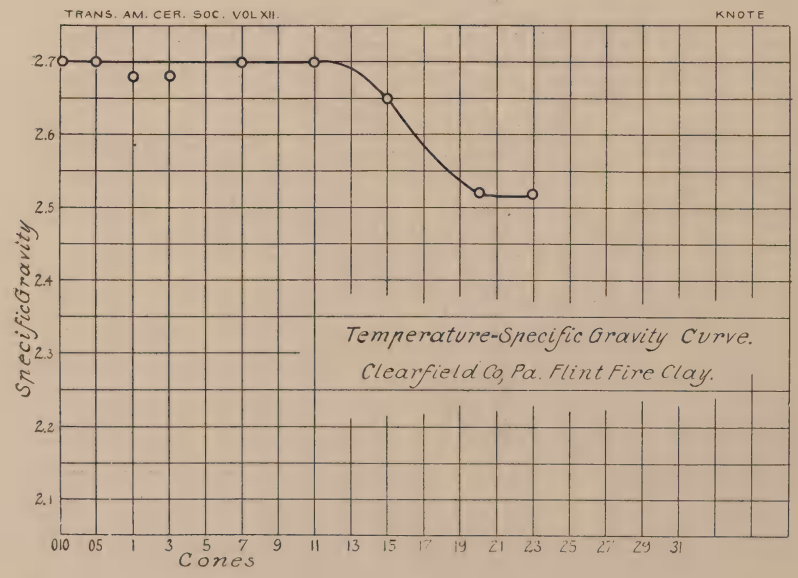
The clay shows itself to be of quite different character from the Olive Hill clay. The specific gravity takes a decided drop about cone 13, but the porosity remains unchanged to a much higher temperature. The fire shrinkage is not high, and the clay seems to swell slightly as the specific gravity drops. This is a condition not frequently met with.

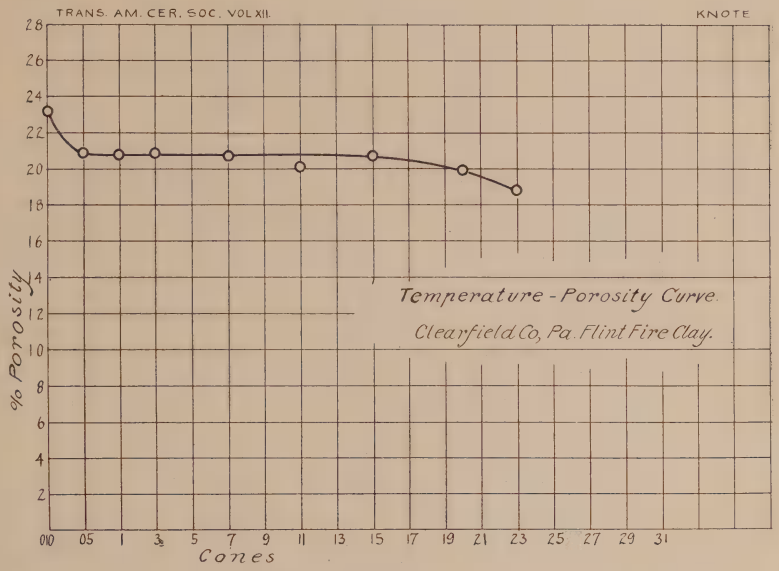
CLEARFIELD CO., PA., FLINT FIRE CLAY.

Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	3.0	2.70	23.0
2	05	4.3	2.70	21.0
3	1	5.6	2.68	21.0
4	3	5.6	2.68	21.4
5	5	...	....	....
6	7	5.6	2.70	21.4
7	9	...	....	....
8	11	5.6	2.70	20.1
9	15	5.0	2.65	21.0
10	20	5.0	2.52	20.0
11	23	5.0	2.52	18.5


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature - Shrinkage Curve.
Clearfield Co, Pa. Flint Fire Clay.
14
12
10
8
6
4
2
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature-Specific Gravity Curve.
Clearfield Co, Pa. Flint Fire Clay.
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones



Savage Mt., Md., Flint Fire Clay.

This clay occurs at the same horizon ascribed to the Clearfield County, Pa., clay, namely, the level of the Mercer coals. It is very similar to the Pennsylvania clay, as the curves show. Occasional pieces show a well marked breccia structure, with irregular sharp edged pieces of various sizes imbedded in a cementing material, which must be very similar in composition to the pieces themselves.

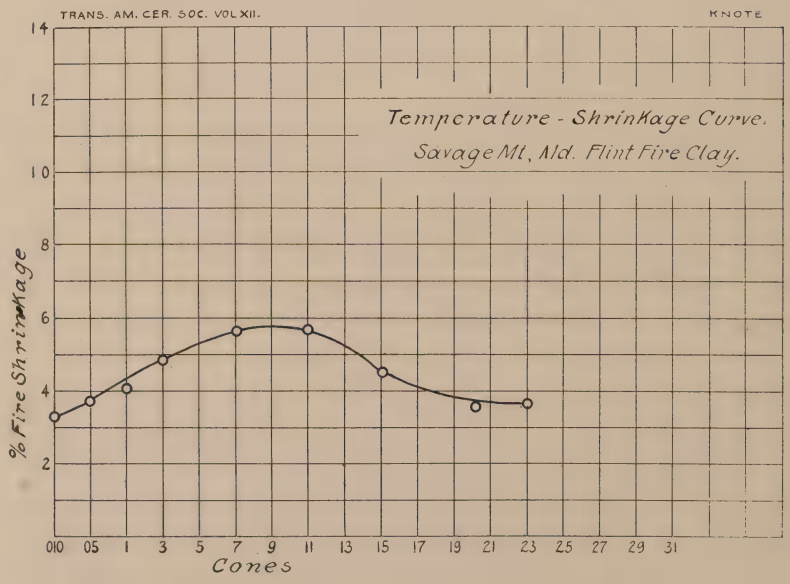
RESULTS.

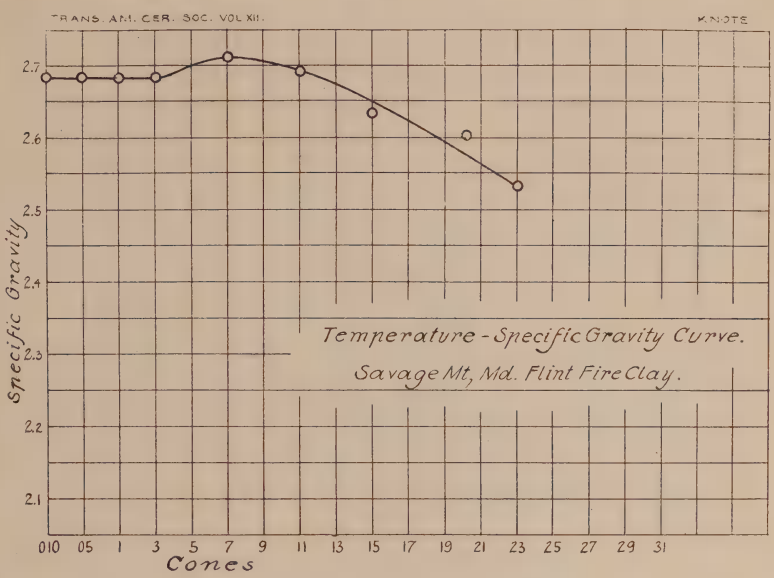
A drop in specific gravity about cone 13, with no decrease in porosity accompanying it, but an increase in volume being shown by the shrinkage measurement, are the same features pointed out in regard to the Pennsylvania clay. This is the second case of flint clays occurring at the same horizon, exhibiting about the same properties, even if separated by a distance of many miles.

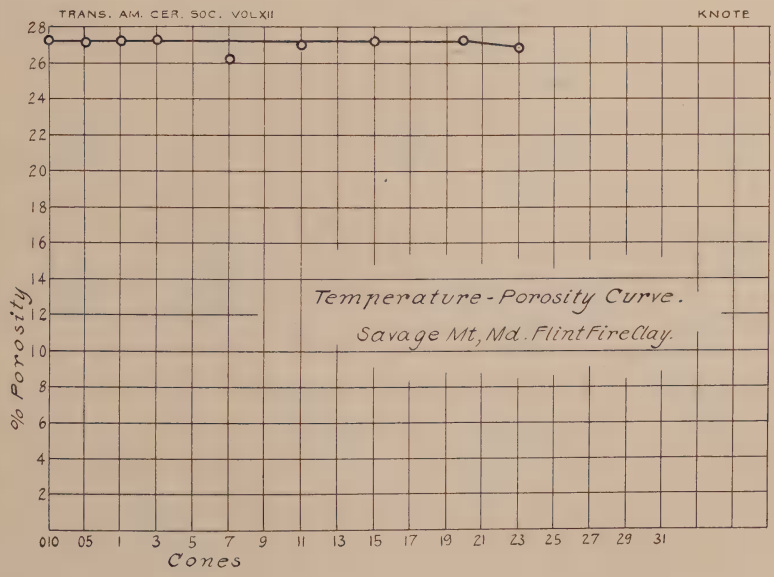
SAVAGE MT. FLINT FIRE CLAY.

Data Obtained on Burned Briquettes.

No.	Heat Treatmenet Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	3.3	2.68	28.0
2	05	3.8	2.68	28.0
3	1	4.0	2.68	28.0
4	3	4.8	2.68	28.0
5	5	...	....	....
6	7	5.6	2.71	26.0
7	9	...	....	....
8	11	5.6	2.69	28.0
9	15	4.4	2.63	28.0
10	20	3.5	2.60	28.0
11	23	3.6	2.53	28.0




TRANS. AM. CER. SOC. VOL XII.
KNOTE
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones
Temperature - Specific Gravity Curve.
Savage Mt, Md. Flint Fire Clay.


TRANS. AM. CER. SOC. VOL XII
KNOTE
% Porosity
28
26
24
22
20
18
16
14
12
10
8
6
4
2
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones
Temperature - Porosity Curve.
Savage Mt, Md. Flint Fire Clay.

Mineral City, Ohio, Flint Fire Clay.

This clay occurs higher up in the geological scale than the clays described, namely, at the level of the Lower Kittanning clay and coal. It shows much more quartz, when examined by the microscope, than the other clays do. The quartz is characterized by very sharp edges, which would indicate a residual origin.

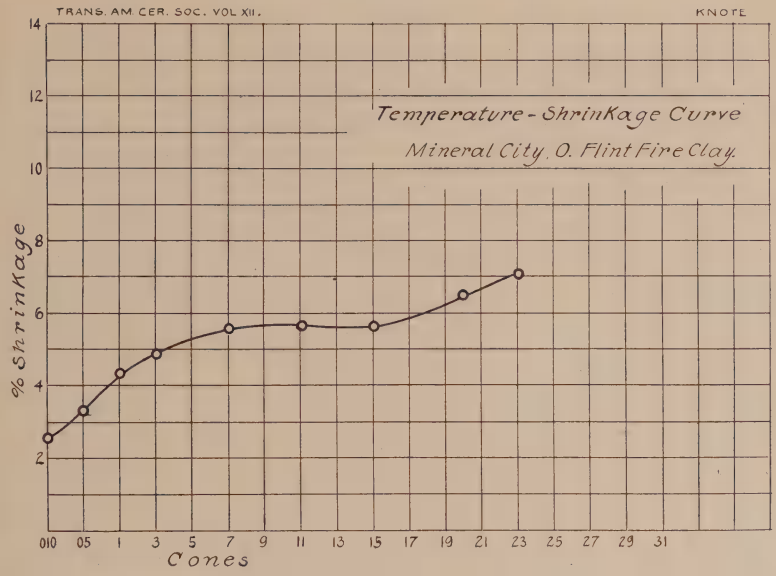
RESULTS.

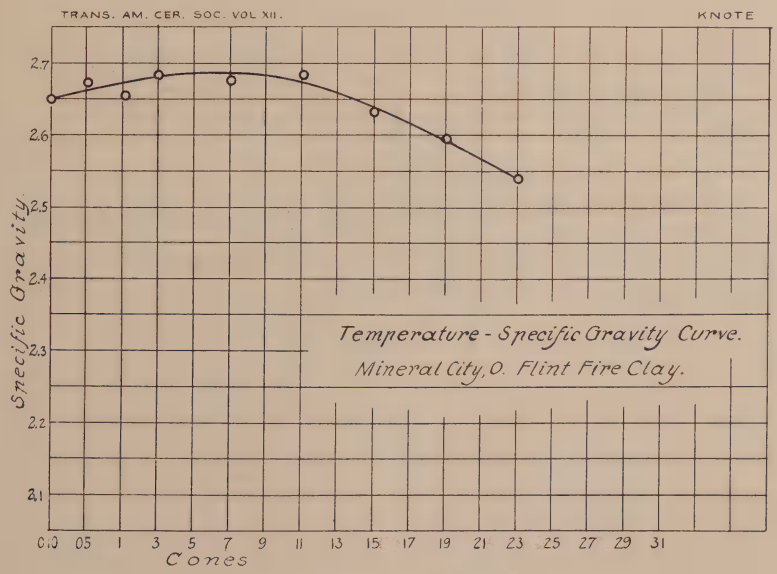
The data shows a drop in specific gravity at about the same temperature at which the phenomenon occurred in the two preceding clays, but the porosity begins to decrease about cone 11. With the decrease in porosity also comes an increase in shrinkage. This is the only flint clay examined whose physical properties changed, as we expected from a study of the plastic clays.

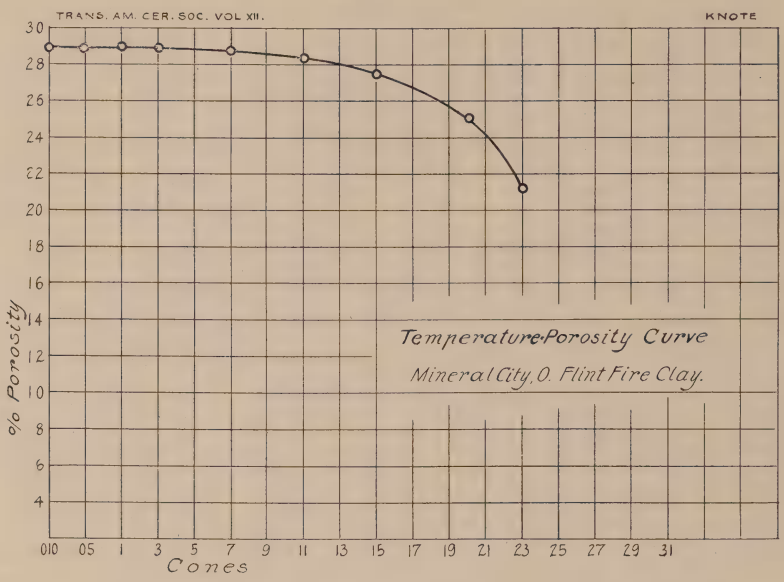
MINERAL CITY, O., FLINT FIRE CLAY.

Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	2.5	2.65	29.0
2	05	2.8	2.67	29.0
3	1	4.3	2.65	29.0
4	3	4.8	2.68	29.0
5	5	...	....	....
6	7	5.6	2.67	28.4
7	9	...	....	....
8	11	5.6	2.68	28.0
9	15	5.6	2.63	27.5
10	20	6.6	2.58	25.0
11	23	7.0	2.54	21.0


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature - ShrinKage Curve
Mineral City, O. Flint Fire Clay.
% ShrinKage
Cones
14
12
10
8
6
4
2
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature - Specific Gravity Curve.
Mineral City, O. Flint Fire Clay.
Specific Gravity
Cones
2.7
2.6
2.5
2.4
2.3
2.2
2.1
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31



Clearfield County, Pa., Plastic Fire Clay.

This clay is not a typical plastic clay, but seems to be more of the semi-flint. It could be regarded as one of the transition clays between the flint and plastic varieties.

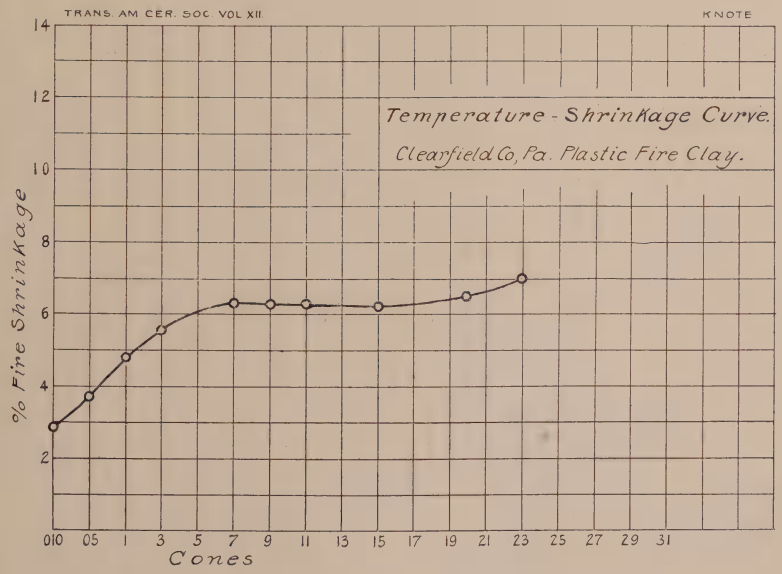
RESULTS.

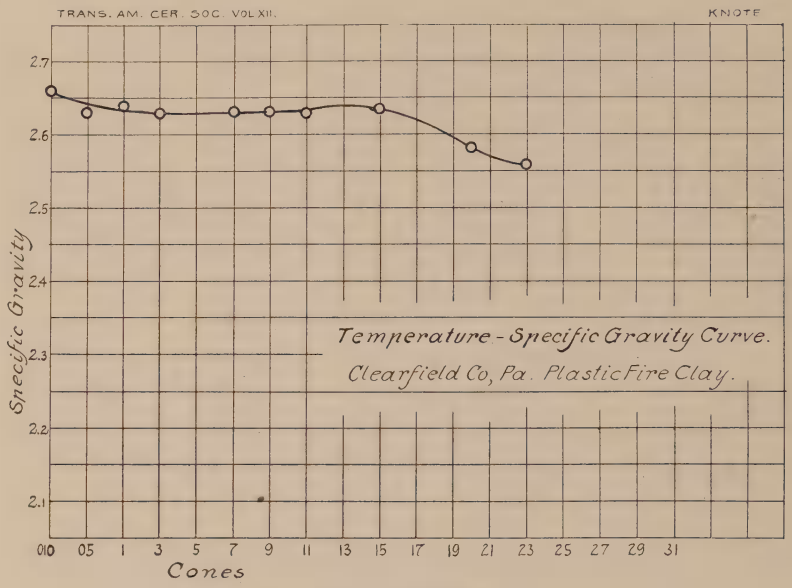
Its behavior is much more that of a flint clay than it is of a plastic. The drop in porosity is greater than that of any flint clay examined, but not as great as that of the plastic clays.

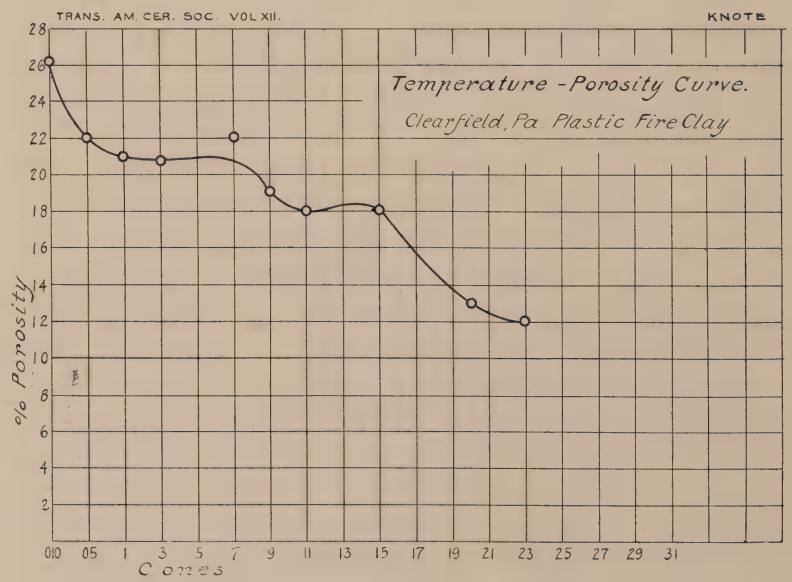
CLEARFIELD CO., PA., PLASTIC FIRE CLAY.

Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	2.8	2.66	26.0
2	05	3.7	2.63	22.0
3	1	4.9	2.64	21.0
4	3	5.6	2.63	21.0
5	5	...	....	....
6	7	6.2	2.64	22.0
7	9	...	....	....
8	11	6.2	2.64	18.0
9	15	6.1	2.64	18.0
10	20	6.5	2.58	13.0
11	23	7.0	2.56	12.0




TRANS. AM. CER. SOC. VOL XII.
KNOTE
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Temperature - Specific Gravity Curve.
Clearfield Co, Pa. Plastic Fire Clay.
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones


TRANS. AM. CER. SOC. VOL XII.
KNOTE
% Porosity
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Temperature - Porosity Curve.
Clearfield, Pa Plastic Fire Clay
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones

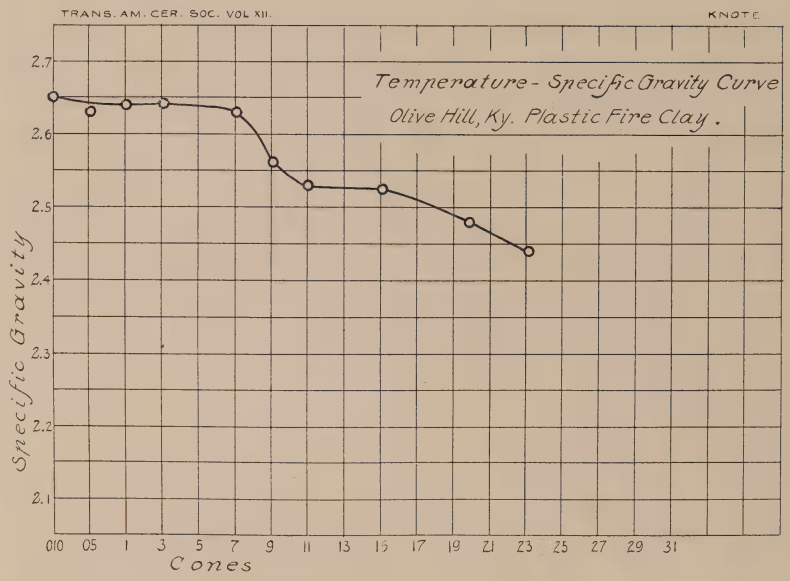
Olive Hill, Ky., Plastic Fire Clay.

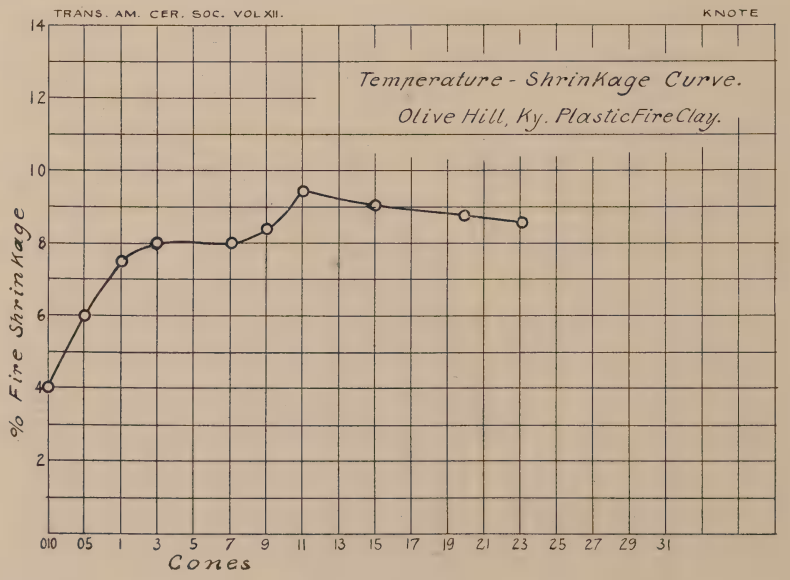
This is a remarkable plastic clay. It does not resemble any of the preceding clays in the least, so far as its physical properties are concerned, but it has very nearly the same chemical composition as the Olive Hill flint clay. Its occurrence and properties are described by Greaves-Walker in Vol. IX, Trans. A. C. S., it being known locally as the Blankenship plastic clay. Occurring in the same vein with a flint clay of almost identical chemical composition, and almost the same cone of fusion, it serves to eliminate most of the factors which have been suggested to explain the difference between plastic and non-plastic clays.

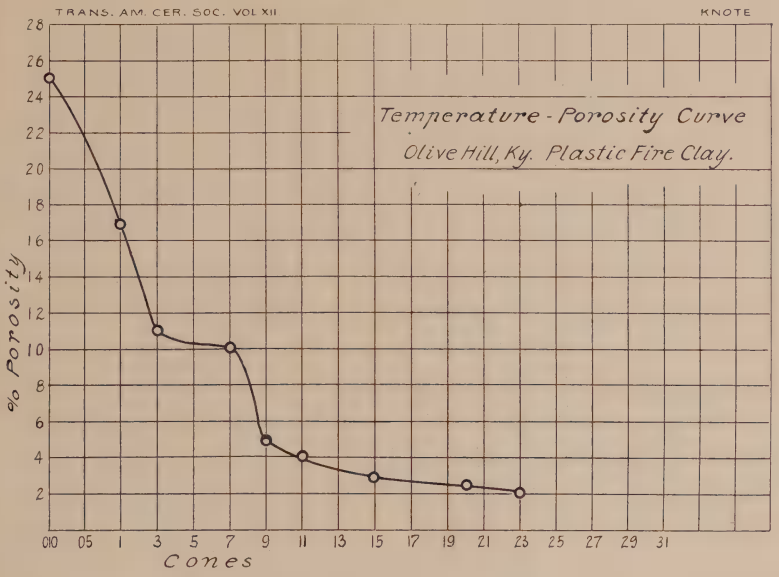
OLIVE HILL, KY., PLASTIC FIRE CLAY.

Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	4.1	2.65	25.0
2	05	5.8	2.64	17.0
3	1	7.5	2.64	14.4
4	3	8.0	2.64	11.0
5	5	...	....	....
6	7	8.0	2.63	11.0
7	9	8.6	2.56	5.0
8	11	9.3	2.54	4.0
9	15	9.0	2.54	3.0
10	20	8.8	2.48	2.5
11	23	8.6	2.44	2.0


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature - Specific Gravity Curve
Olive Hill, Ky. Plastic Fire Clay.
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature - Shrinkage Curve.
Olive Hill, Ky. Plastic Fire Clay.
% Fire Shrinkage
14
12
10
8
6
4
2
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones

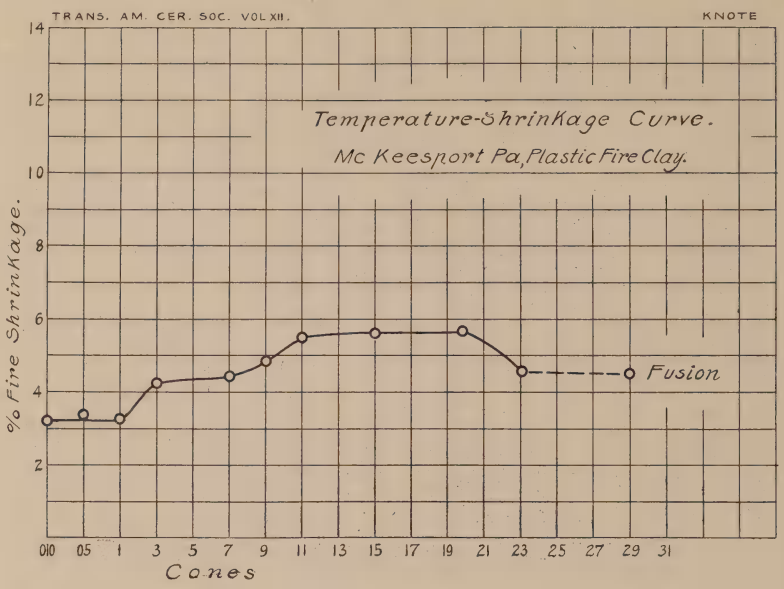


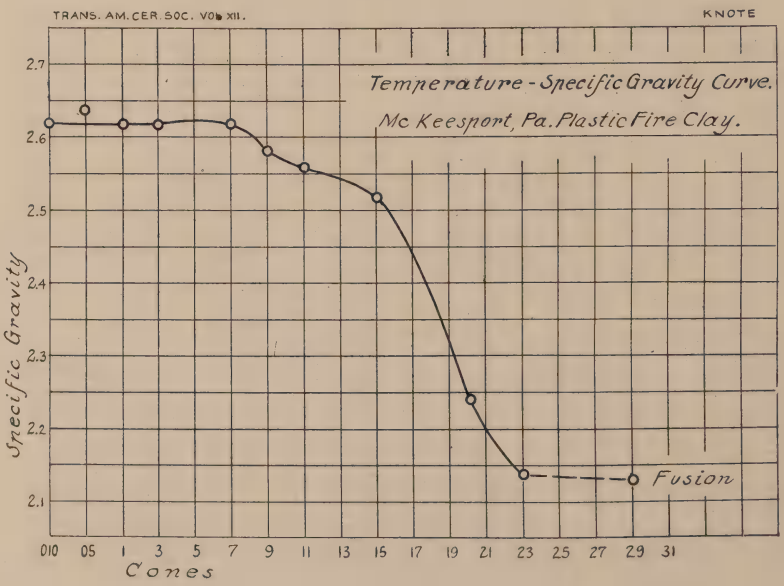
McKeesport, Pa., Plastic Fire Clay.

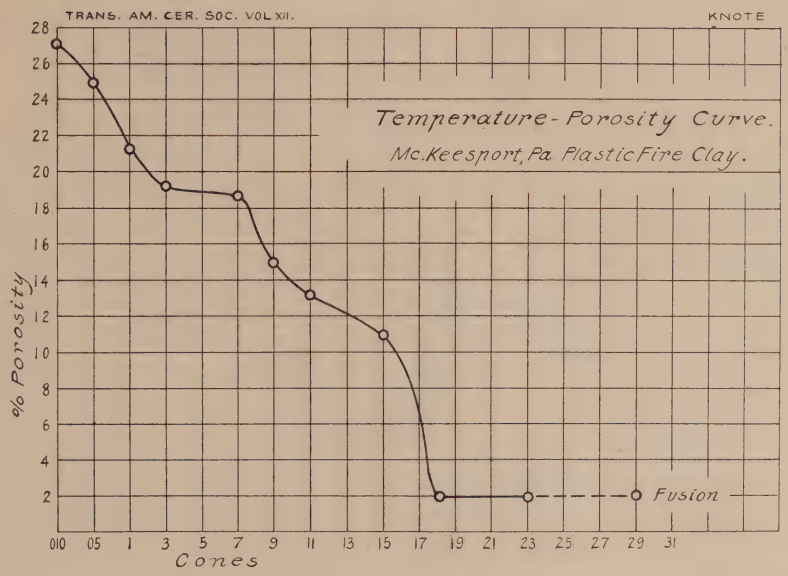
This clay is from the same locality as the flint clay listed as McKeesport, Pa., flint clay. It presents nothing out of the ordinary except that in the raw condition it has more of a shale structure than that of a typical fire clay.

McKEESPORT, PA., PLASTIC FIRE CLAY.
Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	3.1	2.62	27.1
2	05	3.2	2.64	25.0
3	1	3.1	2.62	21.6
4	3	4.1	2.62	19.2
5	5	...	....	....
6	7	4.3	2.62	18.7
7	9	4.9	2.58	15.3
8	11	5.3	2.56	13.4
9	15	5.6	2.52	11.0
10	20	5.6	2.24	2.0
11	23	4.3	2.14	2.0


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature-Shrinkage Curve.
Mc Keesport Pa, Plastic Fire Clay.
% Fine Shrinkage.
Fusion
Cones


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature - Specific Gravity Curve.
Mc Keesport, Pa. Plastic Fire Clay.
Specific Gravity
Fusion
Cones

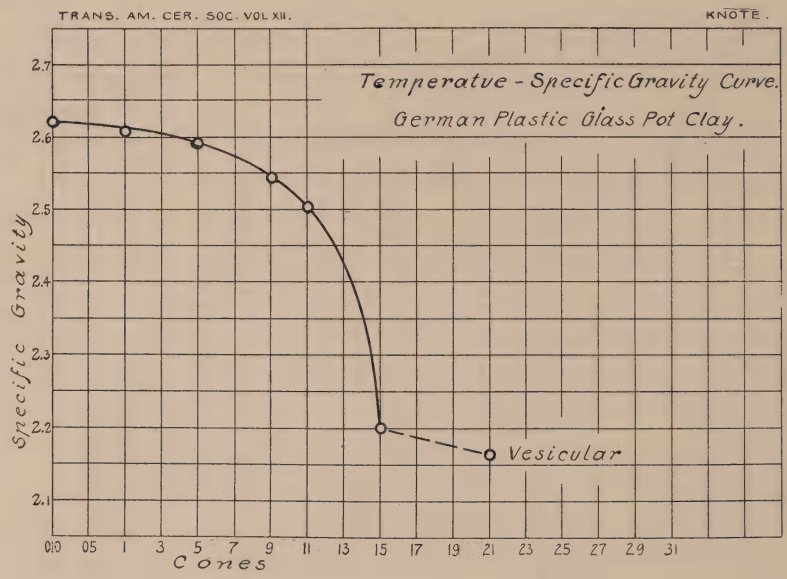


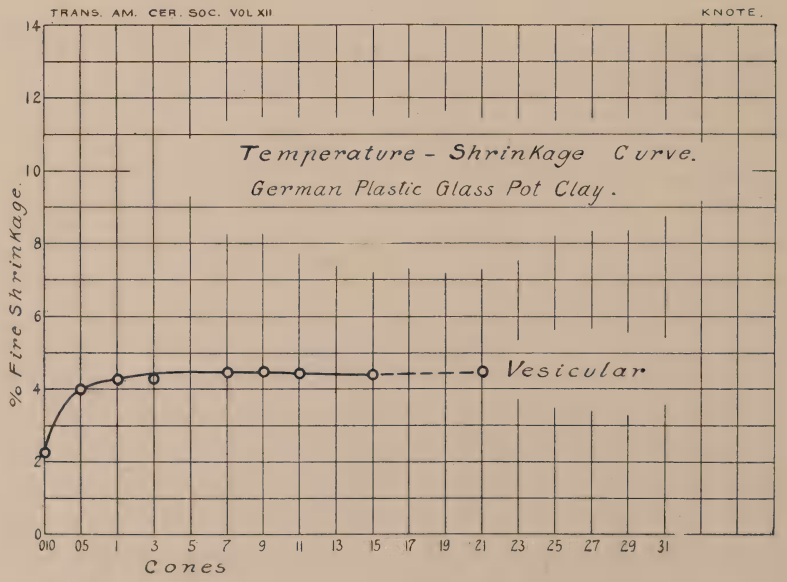
German Plastic Glass Pot Clay.

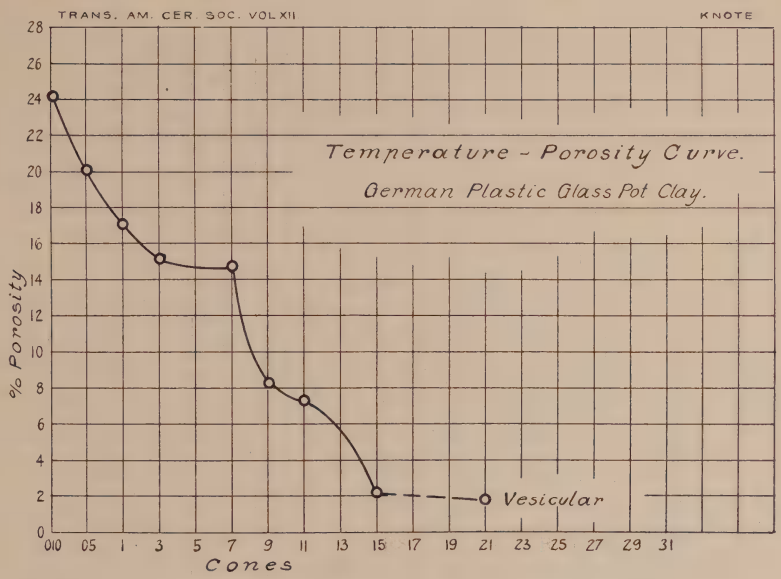
Imported clays are used more or less in the manufacture of glass pots, and as the clay here described is used for this purpose its behavior is of some interest.

Data Obtained on Burned Briquettes.

No.	Heat Treatment Expressed in Cones	Per Cent Fire Shrinkage	Apparent Specific Gravity	Per Cent Porosity
1	010	2.3	2.62	24.4
2	05	2.4	2.62	20.3
3	1	4.3	2.61	17.3
4	3	4.3	2.60	15.8
5	5	...	....	....
6	7	4.6	2.57	15.0
7	9	4.6	2.54	7.7
8	11	4.6	2.50	7.0
9	15	4.2	2.21	2.0
10	20	Vesicular	....	....
11	..	...	....	....


TRANS. AM. CER. SOC. VOL XII.
KNOTE.
Temperature - Specific Gravity Curve.
German Plastic Glass Pot Clay.
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Vesicular
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones

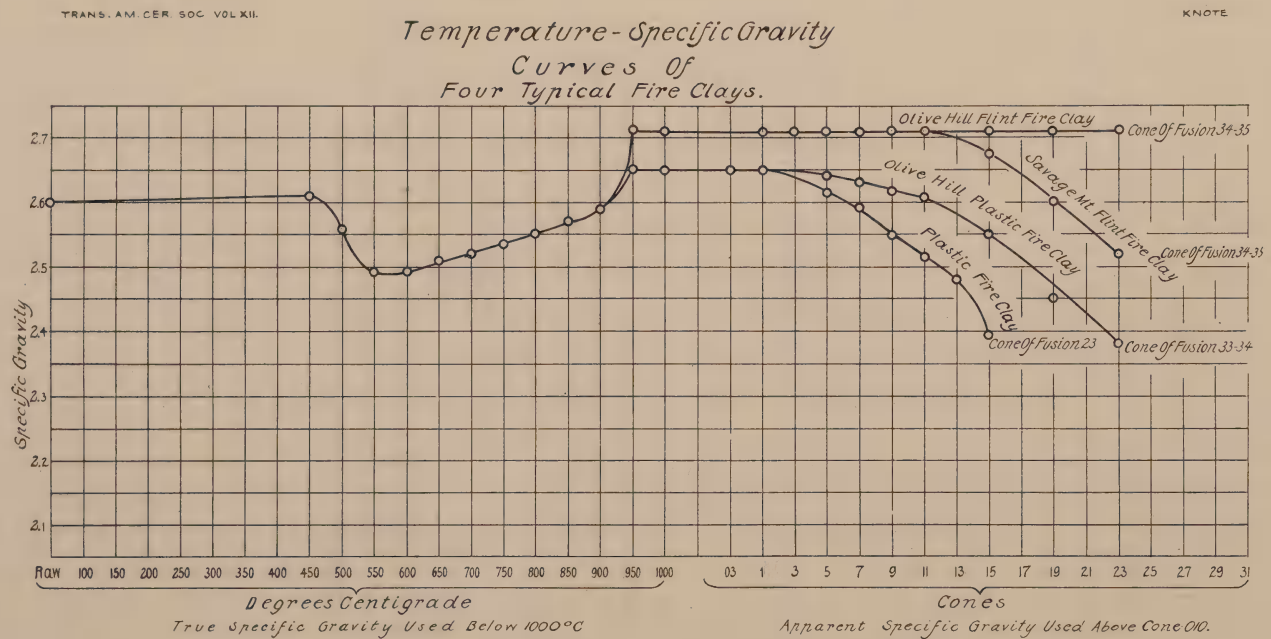

TRANS. AM. CER. SOC. VOL XII
KNOTE.
Temperature - Shrinkage Curve.
German Plastic Glass Pot Clay.
% Fire Shrinkage
14
12
10
8
6
4
2
0
Vesicular
010 05 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones



The foregoing curves show that there is a great difference in the behavior of various flint fire clays, and a sharp contrast between the behavior of flint clays and plastic clays.

General Conclusions.

We here present the specific gravity curves of a number of fire clays, all drawn on one sheet. The specific gravity below 1000° C. is true specific gravity, while that above that temperature is apparent specific gravity.


TRANS. AM. CER. SOC. VOL XII.
KNOTE
Temperature-Specific Gravity
Curves Of
Four Typical Fire Clays.
Olive Hill Flint Fire Clay
Cone Of Fusion 34-35
Savage Mt. Flint Fire Clay
Cone Of Fusion 34-35
Olive Hill Plastic Fire Clay
Plastic Fire Clay
Cone Of Fusion 23
Cone Of Fusion 33-34
Specific Gravity
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Flaw 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000
Degrees Centigrade
True Specific Gravity Used Below 1000°C
03 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Cones
Apparent Specific Gravity Used Above Cone 010.

For the behavior of clays below 1000° C, we have already advanced an hypothesis, which is formed entirely on experimental data. To explain the behavior above cone 010, we have produced no experimental data, but numerous facts have been brought out by others which help us to formulate an hypothesis.

Numerous writers have pointed out that through sufficiently severe heating all clay wares become more or less crystalline in structure. The clay substance is said to break up into one silicate which is rich in alumina, and another rich in silica. The crystalline substance found in porcelains which have been heated above 1350° C has been identified as sillimanite—(Al_2O_3 SiO_2).

Reasoning from these facts, and our own data, we suggest that on dehydration, kaolinite or clay substance breaks down into two silicates, one rich in alumina and the other rich in silica. These silicates are readily attacked by reagents. At about 950° C a pronounced change takes place, the exact nature of which is still uncertain. If Al_2O_3 2 SiO_2 is formed at this temperature, it becomes unstable as the temperature advances, and is decomposed by the action of fluxes, with the formation of a basic and an acid silicate. If no combination of silicates takes place at 950° C, but the change is due to the formation of isomeric compounds, it is not so easy to explain the phenomena so often pointed out. Experiment alone can decide the question as to what really occurs.

The reactions below cone 010 take place at the same temperatures in the case of both plastic and non-plastic clays, since no constituents are involved other than the clay substance itself. But above that temperature, where other constituents act on the clay substance, there is a striking difference, not in what takes place, but in the temperature at which it takes place. Seger showed clearly that this difference in the behavior of the two types of clay is not necessarily due to difference in chemical composition, but in clays of similar composition to a difference

in physical structure. We may assume then that the difference in the behavior of the plastic and non-plastic clays shown above is primarily due to this cause.

In conclusion, the writer wishes to acknowledge his indebtedness to Mr. B. S. Radcliffe and Mr. A. E. Williams for valuable assistance in securing the foregoing data, and to Professor C. W. Rolfe for granting the use of funds and apparatus which made the work possible.

A METHOD OF TESTING CLAYS FOR PAVING BRICK PURPOSES.[1]

BY

G. H. Brown, Pittsburgh, Pa.

Vitrification is usually measured by physical tests as to hardness, porosity, specific gravity, etc., and the vitrification range by the rate at which these vary for a series of temperatures. A clay which has a short vitrification range is generally considered unsuitable for paving brick on account of the impossibility of securing uniform temperatures in the average commercial kiln. While the brick in the top may be marketable, those in the bottom are liable to be unfit for use and vice versa. When vitrification is carried too far a glassy fracture, often accompanied by a vesicular structure, results and toughness is sacrificed. It is hence a pertinent question to inquire whether it is possible to correlate rate of vitrification with toughness. Purdy[2] makes the statement, "we have not been able to distinguish by these physical tests between the clays of 14% and 24% type measured in the per cents loss in the rattler test, nor between the clays that preserve their maximum strength through a wide heat range and those which attain and preserve their maximum strength only within a narrow heat range."

The same author says[3]: "sufficient evidence is at hand to warrant the statement that any clay which vitrified to a porosity of two or three per cent before cone 5 in the heat treatment prescribed in this method of burning test pieces, will be too brittle for use as a paving brick material." Since in the present work the ordinary absorption test was

[1] By permission of the Director, U. S. Geological Survey.

[2] Illinois Geological Survey Bull. No. 9, page 274.

[3] Ibid, p. 274.

used to indicate porosity the results are not strictly comparable with his, yet it was brought out in the case of one clay that the best structure was obtained between cones 4 and 5 with an absorption of less than 1 per cent. This material stood a better abrasion test than any of the other clays tested. Purdy's statement, however, is borne out in another case where the structure is glassy at cone 1.

The value of the standard rattler for paving brick tests is not questioned and, when operated according to specifications, gives fairly comparable results, but the need of a laboratory abrasive test has long been felt. The usual laboratory tests as to hardness, shrinkage, porosity, vitrification range, etc., while giving some indication of the value of a clay for paving brick purposes unless supplemented by an abrasive test, are apt to be misleading. In several instances plants have been erected and operated without first thoroughly testing the clay used, and the product was found to be below the market standard. The use of the larger test is in most cases too expensive and laborious owing to the large amounts of clay required, the size of machine and the liability of having to make changes, the necessity of a large test kiln or the use of a commercial kiln, which in many cases, is not available or not adapted to the clay being tested, and finally, the considerable expense involved.

Laboratory tests as to the abrasive qualities of clay bodies have already been made in several instances, the methods of procedure varying. Ogden[1], in his work on porcelain bodies, adopted circular test pieces $\frac{5}{8}''$x$2\frac{1}{2}''$ in diameter. These were rattled in a small rattler for different periods of time. As his abrasive charge he adopted 200 lbs. of jackstones and 15 lbs. of pebbles.

In the Ceramic Laboratory of the Ohio State University 2 inch cubes were molded by hand, repressed, burned, and rattled in a small mill which had been standardized. This process is apt to be faulty through defects in molding and lack of uniformity due to differences in pressure, etc.

[1] Ogden, Trans. Am. Cer. Soc., Vol. 7, part 3

The cubes tested are sometimes rattled with cubes cut from paving blocks of known abrasion loss.

In conducting researches at the University of Illinois[2] discs were made by batting the clay into a slab between two guides, and passing a roller over the latter so as to obtain uniform thickness, and then cutting with a tin biscuit cutter. The discs were repressed on a hand screw press. This form of test piece was found convenient and adopted for the present investigation. In this work, however, it was decided to work with larger samples, and to use an auger machine of commercial size for the shaping of the discs. Consequently a dry die of circular section was attached to the machine. The die producing a round column was adopted, it being thought that it had some advantages over the cube or block form, which may be summarized as follows:

1. The use of a circular cross section does away with corner friction and, in most shales and No. 2 fire-clays, makes lubrication unnecessary, while dies of different construction and lubrication would be necessary for clays of different flowing qualities.

2. A better structure could be obtained, there being no weak corners to give untrue losses, as would possibly be the case if a square or rectangular die were used.

The investigation planned is very extensive, and the results given in this paper are of a preliminary character. The present work is discussed under the following headings:

1. Character, fineness of grinding, molding, drying, and burning of the test pieces.
2. Description of rattler test.
3. Rate of vitrification of the clays as measured by water absorption.
4. Resistance to abrasion as determined in the laboratory rattler and compared with absorptions.
5. Conclusions.

[2] Trans. Am. Cer. Soc., Vol. XI, page 358.

PREPARATION OF TEST PIECES.

The clays selected for testing are all used commercially in the manufacture of either pavers or face brick. The samples as received were ground and screened, having been taken at the respective yards just before entering the pug mills or presses. In this way a representative sample was secured and, at the same time, some idea of the relative effect of fine and coarse grinding could be obtained. The sample numbers correspond to the following materials:

No. 1, Paving brick shale from western Pennsylvania.

No. 2, Paving brick shale from northern Ohio.

No. 3, Paving brick shale from northern Ohio.

No. 4, No. 2 fire clay used in the manufacture of face brick in southern Ohio.

No. 5, No. 2 fire clay used in the manufacture of face brick in western Pennsylvania.

DRY-SCREENING ANALYSIS OF CLAYS USED.

No.	0—6	6—10	10—20	20—40	40—60	Finer Than 60 Mesh
1	7.91%	19.39%	24.80%	15.03%	7.60%	25.27%
2	.....	9.10	31.40	27.00	10.30	22.20
3	.....	8.85	33.83	23.92	9.25	24.15
4	.....	.....	11.92	33.12	19.95	35.01
5	.....	.....	1.23	10.92	23.18	64.67

It will be noted that shale No. 1 has been passed through the coarsest screen, nearly 8 per cent being of six mesh or larger. Shales Nos. 2 and 3 are somewhat alike in respect to size of grain. The percentage finer than 60 mesh is about the same for the three shales.

The two fire clays are ground finer than the shales, a larger percentage having passed the 60 mesh screen. No. 5, however, was much finer than No. 4, a 20 mesh screen having been used.

The tempering was accomplished in a wet pan, the grinding being long enough to give the proper consistency

No. 1 shale, 16.2% water.

No. 2 shale, 18.0% water.

No. 3 shale, 20.6% water.

No. 4 fire clay, 16.0% water.

No. 5 fire clay, 19.5% water.

From the pan the clay was fed by hand into an auger machine, to which was attached a 3½ inch unlubricated circular die. Care was taken to have this machine approximately full at all times. The solid cylinder of clay was cut into 1-foot lengths and then into discs by means of a mitre-box and single-wire cutter. The first discs were made 1¼ inches in thickness, but later this thickness was found to be not sufficient and 1½ inches was adopted as the standard thickness of the wet disc. No difficulties were encountered in securing a smooth flow through the die in the case of the above clays. The fire clays, however, gave the smoother surfaces when cut by the wire, owing to their having been more finely ground than the shales. The discs were not repressed. The discs were dried in air until leather hard and then in the steam drier, the final drying temperature being 100°C. No drying defects were noted.

The burning was in a down-draft, gas-fired kiln with a burning chamber 32″x 32″x 32″. The time of burning was longer than that of the usual test kiln practice, as it was thought in this way to more nearly approach the conditions of commercial work. The duration of the burns averaged 70 hours. The heat distribution was fairly uniform. The pieces were in good condition when drawn.

Owing to the large number of pieces and limited time available, the usual absorption test was employed for the purpose of expressing the porosity of the burned pieces. The time of soaking in water was 48 hours, the discs being immersed about three-quarters of their thickness in a covered tank. All pieces were dried until constant in weight before rattling and then graded according to absorption.

Rattler Test.

The rattler used was a cylindrical iron mill, shown in Fig. 1, 28 inches in diameter and 14 inches in width, inside measurements. The number of revolutions per minute is 57. Some preliminary work was necessary to secure

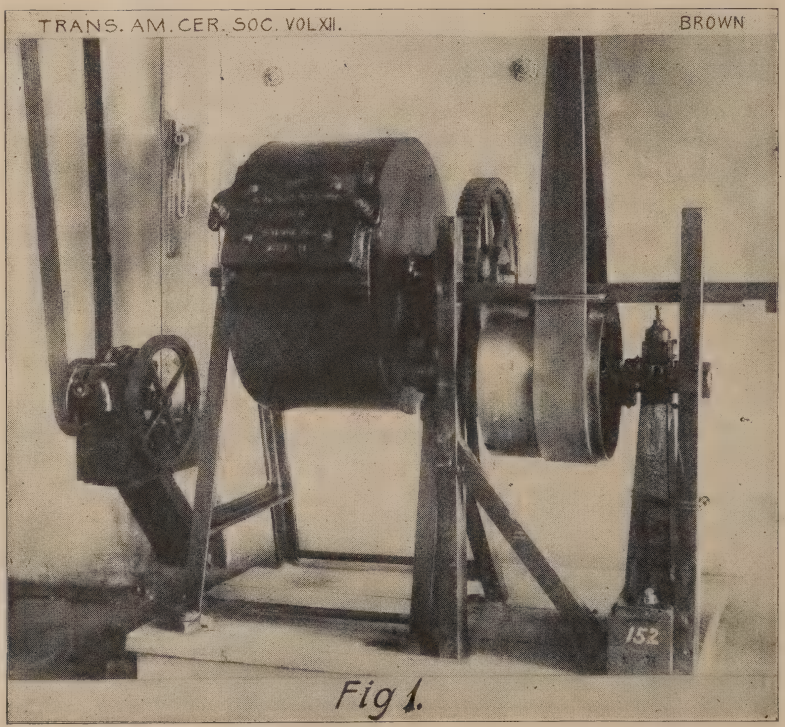


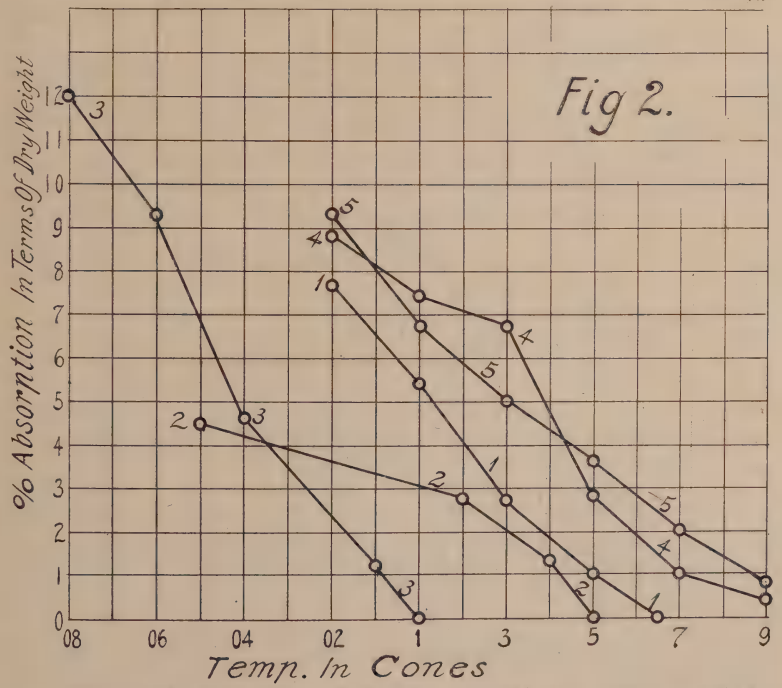
Fig 1.

a rattler loss comparable with that of the standard rattler. The first charge was 170 pounds of pebbles varying roughly from 1½″ to 2″ in diameter, the shapes being more or less irregular. The speed was the same for all tests but the time of rattling was varied. While fairly good results were secured in using this material, it was found that the considerable loss in the weight of the pebbles would be a factor of importance, and hence 1½″ cast iron cubes were substituted. After trying various weights of cubes 350 pounds

was found to give comparable losses, the duration of run being 30 minutes and the number of revolutions, as before, 57 per minute. The shot were weighed and the losses replaced. At the present writing cast iron spheres[1] have been substituted for cubes, it being thought the factor of the wearing away of the corners of the shot and the consequent factor in the abrasive loss will thus be reduced. It is a well-known fact that unless the cubes of a standard rattler are periodically replaced by new shot, erratic results are obtained.

Relation Between Absorption and Temperature of Burning.

As before stated, an ordinary absorption test served



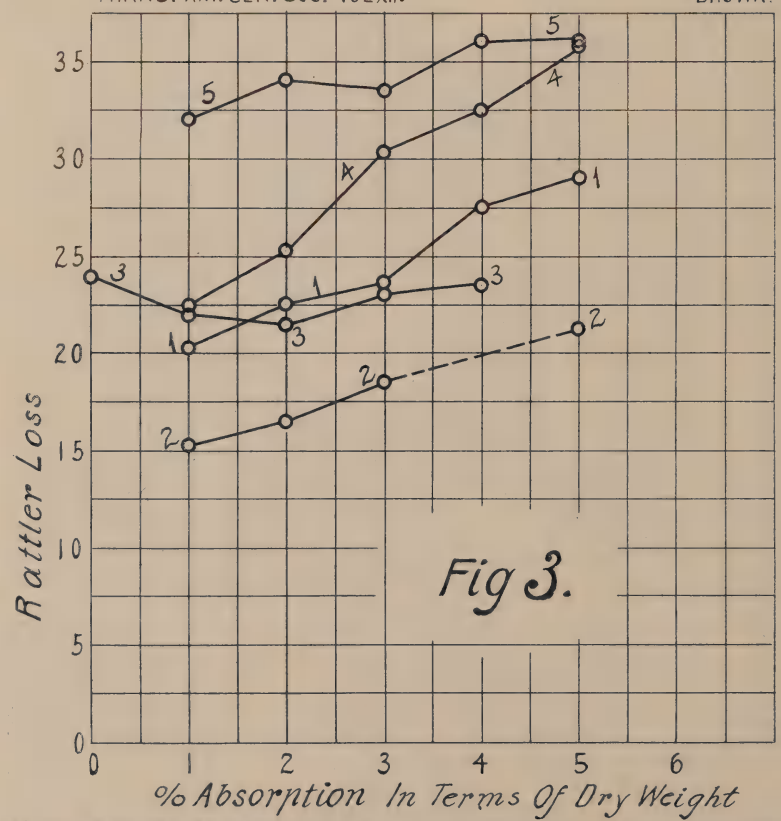
to indicate the porosity of the burned pieces. Draw trials were not used, the absorption being that of the full sized

[1] In this the recent practice of Prof. Edward Orton, Jr., is being followed.

discs burnt to different temperatures. The absorption temperature curves are presented in Fig. 2. The following facts are noted in connection with these curves:

Shale No. 1. The vitrification curve of this clay is fairly good, the drop being gradual from cone 3 to the finishing temperature. It will be noted that this clay does not fall to 1% absorption until cone 4 is reached.

Shale No. 2. The vitrification curve of this clay from 2.8% absorption to 0 absorption is somewhat similar to



that of shale No. 1. The increase in absorption with decrease in burning temperature, however, is more gradual than in the case of shale No. 1.

Shale No. 3 has the most unsatisfactory behavior, as far as vitrification range is concerned, of any of the clays tested, the slope of the vitrification curve being very abrupt. At cone 1 the structure is glassy. At cone 01 the structure is stony. Above cone 1 a vesicular structure is developed. Owing to the very short temperature range, during which this clay has a good structure, it would be exceedingly difficult to produce a uniform product commercially.

Fire Clays Nos. 4 *and* 5. The two fire clays show similarity in the general slope of the vitrification curves, and do not differ greatly in that respect from Shale No. 1. No. 4 is irregular, having an abrupt drop between cones 3 and 5.

Rattler Loss vs. Absorption.

The small number of clays tested thus far do not allow of any important conclusions as to the requisites of a good paving brick clay. Taking up the clays tested in order, Fig. 3, it will be noted that the minimum rattler loss of shale No. 1, showing an increase with increasing absorption, is somewhat large compared with that of shale No. 2. This may be due to several causes. The clay was very coarsely screened, 8% being above 6 mesh size. This clay did not wear so evenly during abrasion as did shale No. 2, and the test pieces had the appearance of being pitted where the coarse grains had been shaken out. The abrasive loss increased uniformly up to 3% absorption, when the increase was rather abrupt. Above 5% absorption the discs did not stand up well, having a tendency to break to pieces. Shale No. 2 possesses more qualifications as a good paving brick material than either of the other two shales, the slope of the vitrification curve being less than that of the two other clays. The dry screen analysis of this clay gives no excessive per cent of coarse grained material. The discs rattled showed a more uniform wearing away than did those in the case of the two other shales. The absorption-abrasion curve is very uniform. No discs

of 4% absorption were tested, and the dotted line was assumed to connect the 3% with the 5% point.

Shale No. 3 presents some erratic results. The dry screen analysis is about the same as shale No. 2. From the vitrification curve it will be noted that the temperature-absorption curve of this clay is very abrupt. At cone 1 the clay had a glassy structure. The rattler losses are high in all cases, but from the curve it will be noticed that the loss decreases with increase of absorption from 0 to 2 per cent. This is accounted for by the exceeding brittleness of the pieces at the higher temperatures. The discs as they came from the rattler did not show a smoothly worn surface, but the losses seem to be due to pieces chipped off during abrasion. As the absorption increased, however, the wearing was more uniform.

The two fire-clays tested were markedly different as to fineness of grains, No. 4 having 12% of 20 mesh material while No. 5 had only 1.23%.

Fire clay No. 4 shows a rattler loss at 1% absorption, about equal to that of shale No. 3. The wearing down of this clay was uniform, the pieces showing very little chipping. Increasing absorption rapidly increases the rattler loss at a fairly uniform rate, but the loss probably would be accelerated with still higher absorption. The rattler losses of clay No. 5 were the highest of any clay tested. Similarly to the case of shale No. 3 with decrease in porosity, the tendency to chip was very great. The discs of 4% and 5% absorption wore evenly, while those of 1, 2 and 3% absorption chipped badly. This cannot be accounted for as in the case of shale No. 3, however, where the glassy structure was much in evidence. Before rattling, the discs had apparently a good structure. The fineness may have had something to do with it, and flaws might have been developed in the drying. This clay is not so plastic as No. 4, and required longer grinding in the wet pan to develop proper bonding power.

As before stated, the number of clays tested has not

been sufficient to make any important conclusions, or absolutely establish the value of the test. It is planned to extend this work over a large field of clays, paying careful attention to the size of grain, the flow of the clay through the die with and without lubrication, the determination of the true and apparent porosities, and the burning behavior.

Conclusion.

From the work done so far it appears that this method of testing produces consistent results as regards the determination of the resistance to abrasion, and it seems to offer a satisfactory laboratory method for this purpose. As far as the tests have gone it seems to show a certain relation between the absorption-temperature, and the absorption-rattler loss curves. The former in a measure predict the latter for the same class of clays, i. e., the greater the drop in absorption per temperature interval the greater will be the resulting rattler loss, the less the toughness. This confirms the statement of Purdy relating to the differentiation between shales for paving brick purposes.

The sizing of the ground material seems to be an important factor in as much as coarser grinding retards the vitrification effect, which with some clays is beneficial, with others detrimental. In clay No. 1 the coarse grinding was carried too far.

This test, like the standard rattler test, brings out clearly the effect of glassy structure. It is evident that what has been said about the absorption temperature curve applies only to shales. A No. 2 fire clay, even though its porosity-temperature curve is very similar to that of a shale, does not for this reason become suitable as a paving brick material. The No. 2 fire clays tested are not suited for this purpose owing to their inherent structure, although no test has been made of the completely vitrified materials.

The thanks of the writer are due to Prof. A. V. Blein-

inger, under whose direction this work was mapped out and executed.

DISCUSSION.

Mr. Lovejoy: Have you sufficient confidence in your test to warrant putting up a 100,000 capacity plant on that evidence alone?

Mr. Brown: No.

Mr. Farnham: Can you predict the rattler strength of a brick from an absorption test? Our bricks show the best rattler test when the absorption is 1%. Is this true of clays in general?

Mr. Brown: All clays that we tested went to pieces in the rattler if they had an absorption of more than 5%.

Mr. Purdy: Not all clays have a straight line curve for absorption and rattler loss. Some clays attain their maximum rattler strength with an absorption of about 5%. Any attempt to increase their vitrification beyond this would decrease their rattler strength. Such clays are, however, an exception rather than the rule.

A METHOD OF TESTING SAGGER MIXES.

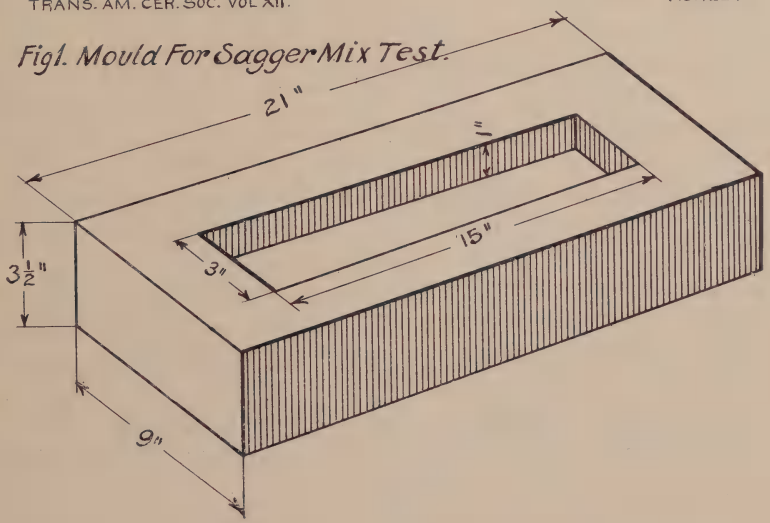
BY

HARRISON EVERETT ASHLEY, Pittsburg, Pa.

This investigation was begun at a time when the saggers at the pottery with which I was connected were proving unsatisfactory in two common respects; they were failing by sagging of the bottoms and by cracking of the tops. Separate tests were devised for each of these conditions.

The sagging is caused by the weight of the ware in sagger and the weight of the sagger bottom itself. It is resisted by the refractory character of the material, and by a sort of drum-head tension whereby the walls of the sagger restrain the circumference of the bottom from moving inward. A logical testing method should show the ability of the material to carry weight without excessive bending.

A set of plaster paris moulds were made of the dimensions shown in Fig. 1.



To make up a mix, usually 500 grams of water was put into a test blunger, then 500 grams of air-dry clay crushed to about 6 mesh, and the blunging continued 30 minutes. On stopping the machine, the mixing vessel was removed, 500 grams of grog (through ¼ inch slot, on 8 mesh wire screen) added, and well stirred in with a wooden paddle. This usually gave a fairly stiff mortar, which was poured and paddled out into the mould. This it usually filled to a depth of about 1¼ inches, that is, it stood about ¼ inch above the top of the mould.

In half an hour or thereabout, most of the excess of water had soaked into the mould, and with a well soaked, square-headed wooden carpenter's mallet, the mix was beaten down into the mould. When about as stiff as sagger mixes are usually worked, it was again beaten down. The pieces were dried at 50° or 60° Centigrade, first on the moulds, then face down out of the mould.

The pieces were fired in common saggers, three to a sagger, in the forebung of a bisque kiln. Cone 8, 9 or 10, usually cone 9, went down in each sagger placed. Each test bar rested on two pieces of firebrick, spaced 12 inches apart. As green saggers are commonly fired with little or no load, these bars were unloaded. When taken from the kiln the deflection was measured by placing a millimeter scale perpendicular to the middle of the bar, and sighting from one end of the bar to the other. The deflections varied from nothing to 20 to 30 mm., at which the bars touched the bottom of the sagger. Taller supports were used in later tests.

If the first burn deflections were not excessive, the bars were again placed with 12 inch span; and a half firebrick, weighing about 1100 grams, placed on the middle, which gave a uniform bending moment for a distance of about 4 inches in the middle of the bar. If results were sufficiently promising three burns were made with a loaded bar.

To test resistance to sudden heating and cooling, pieces about 3 inches by 6 inches in size were broken from

the bars after the bending test. These were put upon a shovel and placed in the front of the fire at the boiler house. When heated to redness, they were drawn out and dropped into a bucket of water. The heating and quenching were repeated until the pieces cracked across.

The grog used, except in special cases, was made from the unsatisfactory saggers first mentioned.

The clays were various clays offered for sale or otherwise proposed for use in saggers. Some of the mixes tried are said to have given excellent results in practice. Others were made to test various theories, or were suggested by the earlier results of the investigation.

A number of clays were first tested alone, as follows:

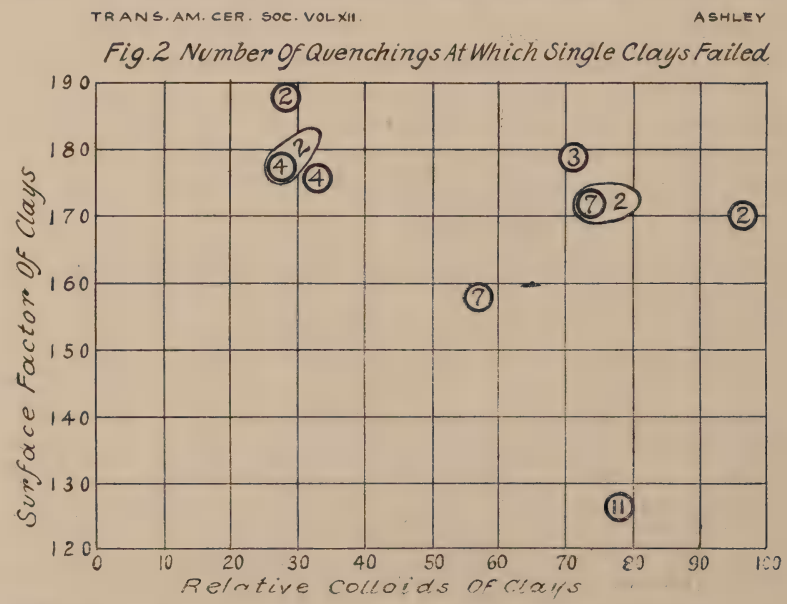
TEST OF SINGLE CLAYS.

No.	Clays	Special	Grog	Water	Deflections in mm.				Quenching Test	Surface Factor of Clays	Relative Colloids of Clays	Per Cent Water Absorbed	Per Cent Linear Shrinkage
					1	2	3	4					
h	500 Ryan No. 1		500	500	T 30				11	126	78	17.63	3.4
z	500 Excelsior B. C. Co. Sagger		500	500	broke				7	172	71	17.38	4.2
aq	500 Excelsior B. C. Co. Sagger	casting addition	500	250+	15	(25) 10	(27) 2	broke	2	172	74	14.84	7.2
an	500 Potter's Sup. Co. No. 4		500	500	T 18	broke			3	179	71	16.39	5.9
al	500 Johnson P. C. Co. No. 1 Ball		500	500	T 20	(31) 11			2	188	28	16.71	6.1
f	500 Knowles No. 12 Ball		500	500	broke				2	170	97	16.69	2.0
e	500 B. B. China Clay		500	500	broke raw					198	22	.....	...
i	250 Edgar Bros. No. 8 / 250 " " " 10		500	500	T 29				7	158	57	16.86	3.2
g	200 Cream, 300 Gray Johnson-Porter No. 23		500	500	T 28				4	176	33	16.54	3.3
bb	500 Hall C. Co. Ga. Sagger (Kaolin)	casting addition	500	300	20	(25) 5	(28) 3	(35) 7	4, 2	178	28	.....	...

The casting addition was alkali. It enabled pieces to be made and placed that otherwise would have been too weak to handle. T signifies that the bars touched the bottom of the sagger, and would have deflected more if permitted. The figures in parenthesis under "Deflections" give the total deflections in 2, 3, or 4 burns. Measurements separated by commas are duplicates. The per cent. water absorbed was determined after concluding the bending tests.

The surface factor is a number *assumed* to be proportional to the total area of the particles in unit weight of clay. The figure for regular colloids assumes to give the relative amounts of colloid matter in the different clays, as determined by the malachite green test.[1]

None of these clays, except when cast, was able to carry much weight in its first burn. To withstand quenching well, Fig. 2 shows in a general way that a single clay



[1] Trans. Am. Cer. Soc., Vol. II, p. 546 (1909); or U. S. Geol. Survey, Bulletin 388, p. 50 (1909).

should have above 50 relative colloids and below 175 surface factor. The Knowles' 12 bar was full of fine shrinkage cracks, which accounts for the low overall shrinkage reported above.

TESTS OF MIXES CONTAINING SAND.

As sandy clays are present in some of the best sagger mixes, the effect of various sizes of sand was tried in the following mixes. The Wedron, Ill., sand used is round grained, and practically of the same nature as the well-known Ottawa, Ill., sand.

No.	Clays	Special	Grog.	Water	Deflections in mm.				Quenching Test	Surface Factor of Clays	Relative Colloids of Clays	Percent Water Absorbed	Percent Linear Shrinkage
					1	2	3	4					
ay	125 Ryan No. 1 Sagger 250 J. P. C. Co. No. 10 R. M. 125 P.S.Co. Wad Clay	100 thru 10 on 40 sand	400	500	T 15	*	...	...	12	152	52	17.4	4.3
aw	The Same.....	100 thru 80	400	500	13	(16) 3	(27) 11	(29) 2	6, 7	152	52	16.8	5.7
ax	The Same.....	100 thru 40 on 80	400	500	T 17	broke	...	...	4, 4	152	52	18.3	5.4
az	150 Ryan No. 1 300 J. P. C. Co. No. 10 R. M.....	150 Sand	400	500	12	(23) 11	(39) 7	...	4, 5	159	56	1.70	5.5

*Broken by accident.

The unclassified fine sand of aw and wholly unclassified sand of az show the best results on the bending test; while the coarse sand of ay shows the best result in the quenching test.

TESTS OF MIXES CONTAINING BITSTONE OR CRUSHED EARTHENWARE.

As a limiting case of quartz sand, No. 6 bitstone was used for grog. It was a disappointment. The fired clay seemed to be wholly without adhesion to the quartz, and

some of the test bars could be crumbled by pressure of the bare fingers.

The weakness of the bars with the larger grains of Wedron sand is evidently from the same cause, lack of adhesion to quartz. The sharpness of the bitstone grains has effected no improvement over the roundness of the sand grains. Quartz, while undoubtedly desirable in a mix, must then be of grains under 10 mesh, and preferably of all sizes, down to something very fine, mixed.

TESTS WITH BITSTONE AND GROUND WARE.

No	Clays	Special	Grog	Water	Deflections in mm.				Quenching Test	Surface Factor of Claye	Relative Colloids of Clays	Percent Water Absorbed	Percent Linear Shrinkage
					1	2	3	4					
bk	125 Ryan No. 1 250 J. P. C. Co. No. 10 R. M. 125 P. S. Co. Wad	100 Bitstone	400	500	22	T crack'd	...	...	...	152	62	18.0	4.2
bi	200 Ryan No. 1 200 Sant Special 150 P. S. Co. Wad	450 Gronnd-ware	...	500	32	(53) 21	...	...	3	123	66	13.9	3.8
bf	Same	450 Bitstone	...	500	20	broke	...	...	3	123	66	12.9	5.5
bj	Same	225 Bitstone 225 G'dw're	...	500	*42	broke	...	...	...	123	66	13.1	4.2
cc	Same	100 Bitstone	350	500	broke	...	...	...	...	123	66	18.0	3.9

*Third attempt. The first two bars made broke in handling before placing in kiln.

Crushed white earthenware proved nearly as unsatisfactory as bitstone, and for the same reason: lack of adhesion to the clay.

Ordinary grog, from crushed saggers, unlike quartz and white earthenware, seems to bond perfectly, and to be indistinguishable from the new clay.

TESTS OF MIXES CONTAINING FIRECLAY.

No.	Clays	Special	Grog	Water	Deflections in mm. 1	2	3	4	Quenching Test	Surface Factor of Clays.	Relative Colloids of Clays	Percent Water Absorbed	Percent Linear Shrinkage
y	300 Johnson-Porter No 10 R. M. 200 Paul Clay Co. ground		500	500	T 21	broke			13	136	59	17.9	4.1
ca	150 Ryan No. 1 300 Paul C. Co. ground 100 Potter's Sup. Co. Wad		450	400	29	broke			9	101	48	16.F	2.0
x	200 Ryan No. 1 325 Paul C. Co. ground 75 Such BB mixt		400	500	T 15	(46) 31			8	105	56	16.4	3.6
w	250 Johnson-Porter C. Co. No. 10 R. M 300 Paul ground 100 Such BB mixt		350	500	T 19	(29) 10	(34) 5	(38) 4	6,3	129	56	14.8	5.5
au	Same as "w"	casting addition	350	350	15 5	(28) 12.5	(32) 4	broke	4	129	66	14.0	7.9
u	250 Johnson-Porter C. Co. No. 10 R. M 350 Paul ground		400	500	T 25				6	118	54	16.1	3.2
ac	200 Excelsior 250 Paul ground 100 Pot. Sup. Co. Wad		450	500	T 23	broke			3	122	50	16 4	2.8
ab	200 Excelsior Clay Co. 300 Paul ground		500	500	T 23				2	116	54	17.2	2.6
r	200 Sant Special Sagg'r 400 Paul ground		400	500	T 19	broke				90	56	16.0	2.4
ae	200 J.-P. C. Co. No. 10 R. M. 250 Paul C. Co. ground 50 Pot. Sup. Co. Wad		500	500	T 22	broke				122	52	18.0	3.0
t	300 J.-P. C. Co. UX 300 Paul C.Co. ground		400	500	T 19	broke				133	38	16.7	3.7
s	200 J -P. C. Co. UX 400 Paul C.Co ground		400	500	T 32					114	39	15.3	3.2
ad	200 Sant Special 300 Paul C.Co. ground		500	500	35					92	58	17.3	2.0

All of these mixes showed excessive deflection in the first burn, mostly touching the sagger bottom (T). Several showed good quenching tests, (in 4 of 6 cases due to use of sandy clay). The mixes, as shown by water absorbed, were fairly refractory. The colloid content was in no case high.

The mixes containing No. 2 fire clay were decidedly inferior. I am not sure why. Mix x had given excellent results when making saggers on the Polk machine; but is apparently unsuited for hand made saggers.

REMAINING TESTS.

Those mixes not included in the preceding groups were tested as follows:

No	Clays	Grog	Water	Deflections in mm. 1	2	3	4	Quenching Tests	Surface Factor of Clays	Relative Colloids of Clays	Percent Water Absorbed	Percent Linear Shrinkage
p	325 Sant Special 175 Hall Clay Co. Georgia	500	500	*	. . .	. . .	. . .	17	136	65	20.8	2.8
p	Repeated	500	500	33	. . .	. . .	. . .	18	136	65	21.3	2.8
br	125 Ryan No. 1 150 Sant Special 325 Duncan Soft White	400	500	12	broke	. . .	. . .	17+	132	48	19.9	4.6
bl	150 Ryan No. 1 200 Sant Special 250 Johnson P. C. Co. Wad	400	500	16	(23) 7	(42) 19	. . .	17	111	57	18.4	3.7
bs	200 Prall Light Sagger 200 Sant Special 150 P. Co. Wad	450	500	20	(29) 9	(39) 10	. . .	16	138	74	20.1	4.3
bc	325 Johnson-Porter C Co. No. 10 R. M. 175 Hall C. Co. Georgia Sagger	500	500	23	(33) 10	(40) 7	(43) 3	15	176	56	20.2	4.9

* Broken accidentally.

No.	Clays	Grog	Water	Deflections in mm. 1	2	3	4	Quenching Tests	Surface Factor of Clays	Relative Colloids of Clays	Percent Water Absorbed	Percent Linear Shrinkage
ap	150 Ryan No. 1 Sagger 250 P'tt'rs Sup Co. No. 4 Sagger 100 Such B. B. Mixture	500	500	T 25	T	...	...	15	161	72	19.7	4.3
q	156 Ryan No. 1 78 Edgar Bros. Co. No. 8 † 78 Edgar Bros. Co. No. 16 114 Sant Special Sagger 143 Such BB mixture	465	500	22	(28) 6	(36) 8	...	3, 12	152	75	18.1	5.4
ag	200 Ryan No. 1 80 Johnson-Porter C. Co. No. 23 Cream 120 Johnson-Porter C. Co. No. 23 Gray 100 Potter's Sup. Co. Wad Clay	500	500	T 19	broke	...	...	12	148	50	18.2	2.9
at	325 Johnson-Porter C. Co. No. 10 R. M. 175 Hall C. Co. Georgia Casting Addition	500	250	19	(26) 7	(29) 3	(33) 4	2, 11	176	56	16.8	4.9
av	125 Ryan No. 1 Sagger 250 Pot. Sup. Co. No. 4 Sagger 125 Pot. Sup. Co. Wad Clay	500	500	T 19	broke	...	...	10	129	61	18.6	4.6
av	Repeated	500	500	25	broke	...	...	...	...	...	...	...
aj	200 Ryan No. 1 200 Sant Special 150 Patter's Sup. Co. Wad	450	500	15	(26) 11	(29) 3	(35) 6	3, 9	123	66	16.3	4.6
...	Fragments of Saggers probably made from "q"	...	...	...	...	...	...	3, 9, 6, 8, 3,	...	...	...	...
l	400 Ryan No. 1 100 P. S. Co. Wad	500	500	20	(68) 48	...	...	9	127	68	17.2	4.7
bh	125 Ryan No. 1 250 Sant Special 125 Potters Supply Co. Wad	500	500	16	(30) 14	(33) 3	(37) 4	8, 6	121	68	18.6	3.7
ak	150 Ryan No. 1 250 Excelsor Clay Co. Sagger 100 Potter's Sup. Co. Wad	500	500	19	broke	...	...	8	150	66	17.7	4.3

† From an actual sagger mix after pugging.

No	Clays	Grog	Water	Deflections in mm. 1	2	3	4	Quenching Tests	Surface Factor of Clays	Relative Colloids of Clays	Percent Water Absorbed	Percent Linear Shrinkage
bn	150 Ryan No. 1 200 Sant Special 250 Sant Wad	400	500	19	(23) 4	(28) 5	(33) 5	7, 2	125	57	19.7	3.2
bm	150 Ryan No. 200 Sant Special 250 Potter's Supply Co. Wad	400	500	15	(29) 14	broke	...	7, 6	125	59	....	...
ah	140 Ryan No 1 140 Edgar 8 and 10 115 Sant Special 140 Such B B Mixture	465	500	26	(42) 16	....	...	6	142	71	19.6	3.3
o	250 Sant No 9 150 Hall Georiga Sagger 100 Potter's Sup. Co. Wad	500	500	T 20	8.5	3.5	..	3	166	28	11 0	5.4
o	Repeat	500	500	....	.....	.....	.....	5	...	.....	.....	...
af	300 Ryan 200 Potter's Sup. Co. Wad	500	400	15	broke	....	...	5	129	57	18.4	3.2
ar	175 Ryan No. 1 88 Edgar No. 8 88 Edgar No. 10 † 144 Johnson Porter C. Co. No. 23 Mixt 175 Excelsor B. C. Co Sagger	330	500	17	(18) 1	(25) 0	...	2, 4	158	62	14.9	7.5
as	The same, with casting addition	330	350	16	(20) 4	(22) 2	(23) 1	3, 4	158	62	14.1	6.3
bp	150 Ryan No. 1 200 Sant Special 250 Duncan Soft White	400	500	10	(20) 10	(35) 35	...	2, 4	129	56	....	...
bq	125 Ryan No. 1 150 Sant Special 325 Johnson-Porter C Co. Wad	400	500	15	(24) 9	(29) 5	(30) 1	3, 3	109	50	18 8	4 5
cb	175 Ryan No. 1 175 Hall Georgia Sagger 175 Sant Special Sagger	475	500	25	(30) 5	(41) 11	...	3, 3	139	63	20.8	3.7

† From an actual sagger mix after pugging.

No.	Clays	Grog	Water	Deflections in mm.				Quenching Tests	Surface Factor of Clays	Relative Colloids of Clays	Percent Water Absorbed	Percent Linear Shrinkage
				1	2	3	4					
aa	400 Excelsior Ball Clay Co. Sagger 100 Potter's Sup. Co. Wad. . . .	500	500	T 17	(35) 18	. . . .	. . .	. . . .	164	65	17.8	5.8
on	200 Sant No. 9 Ball 200 Sant Special Sagger 100 Potter's Sup. Co. Wad. . .	500	500	20	(40) 20	. . . .	. . .	. . . .	149	51	18.3	3.6
bg	125 Ryan No. 1 250 J. P. C. No 10 R. M. 125 P. S. Co. Wad.	500	500	20	(40) 20	. . . .	. . .	. . . .	152	62	18.3	3.7
bo	125 Ryan No. 1 150 Sant Special 325 Potter's Sup. Co. Wad. . . .	400	500	18	broke	. . . .	. . .	. . . .	126	51	19.2	3.2
bd	175 Ryan No. 1 175 Johnson-Porter No 10 R. M. 175 Hall Clay Co. Georgia. . . .	475	500	28	broke	. . . .	. . .	. . .	160	61	20.6	4.2
k	150 Knowles No 12 Ball 250 Poole B B China 100 Potter's Sup Co. Wad. . . .	550	500	T 25	. . . .	. . . .	. . .	. . . .	177	45	20 0	2.8
ao	350 Potter's Sup. Co. No. 4 150 Such B B Mixt.	500	500	T 27	. . . .	. . . .	. . .	. . . .	176	69	20.6	3.9
v	325 Sant No. 9 Ball 175 Hall Clay Co. Georgia	500	500	T 20	broke *	. . . .	. . .	. . . .	187	29	17.7	5.3
d	400 Johnson-Porter C. Co. U. X. 100 Potter's Supply Co. Wad.	500	500	‡	. . . .	. . . .	. . .	. . . .	176	34	. . .	. . .
n	200 Sant No. 9 Ball 300 Hall C. Co. Georgia No. 2	500	500	‡	. . . .	. . . .	. . .	. . . .	184	28	. . . .	. . .
am	350 Johnson-Porter C. Co. No. 1 Ball 150 Snch BB. Mixt.	500	500	‡	. . . .	. . . .	. . .	. . . .	182	39	. . . .	. . .
j	150 Knowles No. 12 Ball 350 Poole BB. China.	500	500	‡	. . . .	. . . .	. . .	. . . .	190	45	. . . .	. . .
ba	200 Ryan No. 1 Sagger 300 Hall Clay Co. Georgia. . . .	500	400	‡	. . . .	. . . .	. . .	. . . .	157	48	22.0	2.5

*While being handled with ordinary care before second burn. ‡ Too weak to handle raw.

The quenching tests of the last table have been assembled in the following tables:

SUMMARY OF QUENCHING TESTS

Surface Factor	Stand over 5 Quenchings	Stand less than 5 Quenchings* or not tested	Surface Factor	Stand over 5 Quenchings	Stand less than 5 Quenchings* or not tested
Above 100 to 110...	0	1	Above 150 to 160...	1	4
Above 110 to 120...	1	0	Above 160 to 170...	1	2
Above 120 to 130...	6	3	Above 170 to 180...	1	3
Above 130 to 140...	3	1	Above 180 to 190...	0	4
Above 140 to 150...	3	1			

Relative Colloids	Stand over 5 Quenchings	Stand less than 5 Quenchings or not tested*	
Above 20 to 30.....	0	3	
Above 30 to 40.....	0	2	
Above 40 to 50.....	2	4	
Above 50 to 60.....	4	4	
Above 60 to 70.....	6	6	(5 of these have sur. factor above 150)
Above 70 to 80.....	4	0	

* Because of excessive deflection in the first burn, the quenching test was omitted in numerous cases.

From this tabulation, is appears that the clay mixture of a good sagger mix should have a surface factor below 150, and relative colloids above 50, or preferably above 60.

The clays were more homogeneously mixed in my tests than when they leave a pug mill.

QUENCHING TESTS ON SAGGERS.

Fragments of actual saggers have been tested by the quenching test as follows:

Failed at:	Resembles most Closely	Which failed at
.....	ar *	2, 4
3, 9, 6, 8, av. 6	q *	3, 12
5, 6, 6, , av 6	av	10

* From an actual sagger mix after pugging.

CLASSIFICATION OF CLAYS.

The clays mentioned in this paper may be classified very roughly as follows:

Sandy.

Potters' Supply Co., Wad.
Johnson-Porter Clay Co., Wad.
P. F. Duncan, soft white.
J. R. Such, B. B. mixture.

Tough Vitrifying.

P. L. Ryan No. 1 Sagger.
Jas. P. Thrall No. 1 Light Sagger.
Geo. Knowles & Sons No. 12 English Ball.

Weaker Vitrifying.

Edgar Bros. Co. No. 8 and 10 Sagger.
Sant No. 9 Ball.

Intermediate Clays.

Potters' Supply Co. No. 4 Sagger.
Excelsior Ball Clay Co. Sagger.

Weaker Intermediate Clays.

Paul Clay Co., Ground Sagger.
Johnson-Porter Clay Co., No. 1 Ball.
Johnson-Porter Clay Co., UX Sagger.
Johnson-Porter Clay Co., No. 23 Sagger.

Tough Rather Refractory Clays.

Sant Special Sagger.
Johnson-Porter Clay Co. No. 10 Run of Mine.

Kaolins.

Hall Clay Co. Georgia Sagger.
J. Poole B. B. English China.

Cramer[1] worked out a similar testing method to this, using bars of clay or mixture 25 cm. long, 2 cm. wide, and 1 cm. deep. All the burns except the last were made with the bars lying upon a flat plate. In the last burn the bars rested on sharp edges 23 cm. apart. Thus to get the effect of five burns, five duplicate bars would be made, of which one only rested on the end supports in any burn.

He found quite different results with different cases. Some clays became less inclined to bend after repeated firings, some became more inclined to bend. There was no relation between the cones at which the clays became tight and the tendency to bend. Clays of low vitrification point often showed no more tendency to bend than those of high vitrification points.

Stormer[2] has made tests that show when the amount of grog in the mixture is varied from 50 to 90 per cent. of the total, that the tensile and compressive strength of the raw and fired mixtures are nearly the same with 50 or 60 per cent. grog, they decrease but little with 70 per cent. grog, and show a decided drop usually with 90 per cent. grog.

The best sagger mix should contain as much and as coarse grog as is practicable to work. A certain proportion of sandy clay with not coarser than 10 mesh grains seems to add greatly to the ability to withstand sudden changes of temperature; though a highly kaolinitic mix may be equally good at the beginning, and is possibly more enduring, (according to Dr. Mellor).

Coarse quartz and ground ware, of low absorption, fail to bond properly with the clays.

A water absorption of 16 to 20 per cent. is shown by good mixes. The toughest clays available should be used for most of the mix. The relative colloids should exceed 50 or 60, and the Jackson-Purdy surface factor should not

[1] Handbuch der gesammten Thonwaarenindustrie von Bruno Kerl. Dritte Auflage. Tonindustrie-Zeitung (1901), p. 706; (1902) p. 300 and p. 1065; (1901) p. 1628 and 1699.

[2] Tonindustrie-Zeitung 33, 1524-1528 (1909).

be greater than 150, when the overflow of the elutriating apparatus carries all clay of less than 0.01 mm. diameter.

I am indebted to Mr. Joshua Poole, manager, who took a lively interest in these tests; and also to many workmen, especially Messrs. Jackson and Stanley, boiler firemen, who participated in the quenching tests.

DISCUSSION.

Mr. Binns: Mr. Ashley has given us a paper on tests of sagger mixtures, and his main point, you will remember, was keeping the grog for the most part constant in testing the different clays. He also examined these clays from the point of view of the surface factor and of the colloidal content, and he came to certain conclusions that for the most part the clay which had the coarsest grain in the clay itself and the highest colloid content was the most satisfactory sagger clay. In other words, that a coarse-grained plastic clay was the clay needed, and you will recall what he said about it. Let us have a discussion on this. Sagger making is a vital point in a great many branches of our industry. There is more money thrown on the dump in saggers than almost anything else.

Mr. Simcoe: I would like to ask Mr. Ashley why he makes this quenching test? What relation has it to the actual condition to which we subject the sagger?

Mr. Ashley: The quenching test is intended to represent in a fashion the sudden heating and cooling to which saggers are subject when the firing is started in the kiln or the doors are pulled down, or corresponding to the baiting of the fires. We feel quite sure that one of the causes of losses of saggers is the sudden rushing of cold air against them; and this heating and cooling gives them strains of similar nature that would tend to break them up.

Mr. Simcoe: You plunge them into water, do you not?

Mr. Ashley: Yes, that is merely a way of hurrying things up.

Mr. Simcoe: Why didn't you put weight on your trials, subjecting them to this condition also?

Mr. Ashley: In the first burn the bars were fired without any weight, but in the second and subsequent burns the weight, consisting of a half brick, say about 1100 grams, was placed at the middle of the bar, so that they were loaded in all the burns subsequent to the first burn.

Mr. Binns: I would like to ask Mr. Ashley in that connection whether he considers that quenching test, with a subsequent heating of the piece still wet, is analogous to the strains the saggers would undergo in use?

Mr. Ashley: I think they are. It is a harsher treatment, but of a similar nature to what they would receive in use. It is a severer treatment and brings more quickly the disruption of the clay.

Mr. Binns: That is probably true. But is the behavior analogous, in other words, is the severer treatment the best way to test the clay? Would it not be possible that a clay might resist a fair strain for a long time and yet go down under an unfair strain, whereas a clay might equally resist the unfair strain but not unequally resist the fair strain? I have no experience along that exact line, but I want to know what Mr. Ashley's view is of the value of that test, whether it is really analogous to an ordinary usage test? Has any fact been brought to light that can help you in the comparison?

Mr. Ashley: I might say that the mix that was being used before the tests were started gave a very unsatisfactory result in these tests, and the mix which was adopted, a mix which gave a very fair showing in these tests, has since been used with very satisfactory resuts in the life of the sagger in the pottery. So that it proved a step in the direction of satisfactory sagger mixtures.

Mr. Binns: That is what I wanted to get at. In all test work we want something that will give us results

which are comparable to those of practice. Some of you must have views on the selection of clay for sagger purposes. What guides you, gentlemen, in the selection of a sagger clay? Why do you use a particular clay in preference to another?

SOME GLOST LOSSES IN THE EARTHENWARE INDUSTRY AND THEIR CORRECTION.

BY

ARTHUR E. MAYER, Beaver Falls, Pa.

The losses occurring in this industry may be divided into three stages, as follows:

1. The loss in the green state,
2. The loss in the biscuit state,
3. The loss in the glost state.

The last we will consider as embracing the time between leaving the glost kiln and the packing of the finished product.

In the green state the finished ware is carried into the green room, and the potter is paid for his ware upon its safe delivery there. The kilnmen then carry the ware to the biscuit kilns where it is placed in saggers, and practically all loss in the green state is due to them. A certain amount of this loss, however, is excusable on account of the fragility of the ware, but it should not exceed .5% of the total amount handled by them.

In the biscuit state the loss is due mostly to one of three causes:

1. Poor potting,
2. Poor firing,
3. Careless handling in drawing and brushing.

With careful attention, the average biscuit loss should not run over 4 to 4.5%, while it may run up to 7 or 8% without assuming alarming proportions. In practice, the average day's loss may run as low as 2.5% and as high as 10%, but generally, in the latter case, with the indication that some class of ware was running particularly bad.

The glost loss is due to many causes which will not be enumerated here, but later explained with a method of their correction.

In the glost ware we have three grades:

1. Run of kiln,
2. Thirds,
3. Lump.

Run of Kiln is the best ware, which must come up to a high standard, and it usually sells for about 60-and-10% off the standard list.

Thirds compose the ware that is not quite good enough for Run of Kiln and have such defects as small biscuit and glost nips, clay cracks, etc. These usually sell for 70-and-5% off the list.

Lump is composed of the rest of the ware that is broken, cracked and very badly nipped. This sells usually at something less than 90% off from the list. From the rapid rate at which the price of ware diminishes, it behooves the management to turn out as much Run of Kiln ware as possible. With careful attention and very favorable conditions, the ware should run from the average glost kiln about 90% R. K., 9¼% Thirds and ¾% Lump. The loss should not be considered as reaching alarming proportions until it is more than 14% Thirds and 1% Lump.

For the sake of convenience, the cause of loss has been divided into several sections, so that it may be more systematically studied and the responsibility be placed with the proper person or department.

LOSSES IN THE GREEN STATE.

Let us consider losses caused by some fault of the body, and under this head one of the most important causes is "dunting."

Dunting is due partially to the body containing too much non-plastic materials, or the rapid cooling of the glost kiln, or perhaps more correctly stated the *combined*

action of these two. It has at first the appearance of a crack, but if more carefully examined it will be found to have comparatively smooth sides, and the line of division usually describing the form of an oval or spiral. It has been suggested that the smoother the sides of the division, the greater the temperature at which it occurred; and this seems quite a logical circumstance for, when a piece of ware approaches a semi-viscous condition and is opened up, it would be smoother than when torn apart at a lower temperature, at which time it would have more of a granular structure.

The *cure* for dunting, if it occurs in alarming quantities should mean a re-construction of the body by replacing some of the non-plastic materials for plastic ones, such as plastic clay, and thus giving the resulting composition of the body a greater tenacity. The kiln should be also cooled more evenly, thus eliminating the damaging uneven strains. It is usual that only the heavy class of ware dunts, such as dishes, basins and large bakers, as well as nearly all sizes of heavy hotel ware.

It is quite often the case that slower cooling alone will prove a remedy for this defect, and should be first tried before re-constructing the body.

Crooked Ware in the glost state often results from the body, and when it comes from this cause it is often due to the excessive use of some one or more of the softer fluxes such as magnesia, lime or soda. When this is the case, they should be reduced in quantity and the necessary vitrification obtained by means of one of the milder fluxes such as potash introduced by means of good orthoclase feldspar.

Sometimes it happens that ware is pinned too close to the edge, either purposely or because the pins are not the correct length. This should be carefully watched and placed properly. For such ware as plate, ½ to ¾ inch from the edge is a proper position, and for ware like large bakers, ¾ to 1 inch. The heavier the piece of ware, the

farther from the edge it should be pinned on account of the excessive strain caused by its weight.

Sometimes the loss may occur from the fault of the fireman when he lets one-quarter of his kiln get away, and the excessive heat causes the plate to sag, or go out of shape. A sudden heat caused by shutting the doors up too quickly after a baiting will also do much damage in this same way.

Dipping. Some of the losses that occur when the glaze is not in good condition on a piece of finished ware are due to the fault of the dipper, and some are not under his control. He should see that the glaze is as even as possible, no unpenciled finger marks left and not too heavy or light a coat.

The weight of the coat of glaze is dependent on three things:

The porosity of the ware,
The length of time immersed, and
The specific gravity, or dipping weight of the glaze.

It is only by the proper adjustment of these three factors that the correct dip can be obtained. It is not always the fault of the dipper when the ware does not come out evenly dipped, and a good example of this is found in such articles as oyster bowls, which are ring ware and placed above the bags in the kiln. In bringing the biscuit kiln up to the proper temperature, the fireman has perhaps closed the door too soon after a baiting, or in some manner flashed the ware around the bags, causing the near side of the piece of ware to be so hard it will scarcely absorb any water at all, while the other side is softer and perhaps in good condition. Since the porosity is a great factor in a coat of glaze, it will be readily seen that the two sides cannot be given an equal coat.

Ropey glaze is another difficulty that is out of the power of the dipper to remedy without resorting to chemical means. A ropey glaze is one which, after immersion

and upon being shaken, will not throw the excess glaze off the rim of the ware, but collects in a pool on the edge. Upon being fired, the edge is heavily dipped and often runs. This can be remedied by adding sulphate of magnesia in quantities of .4 to .8%, depending upon the amount of free akaline salts present in the glaze.

LOSSES IN THE BISCUIT STATE.

Biscuit ware-house losses which make themselves apparent in the glost are numerous. In this department, all losses due to causes in the former part of the process should be detected while brushing, and should they fail to do this they are not properly performing their duty, and as a result allow their losses to increase the glost loss. Ware is often hurriedly or carelessly brushed, and when it is sent to the dipper it often contains dirt and sand. Part of this sand sticks to the ware and the rest is washed off by the glaze, which sticks to the next piece of ware dipped, and as a result a little carelessness will cause considerable trouble. Because a piece of ware has a small edge crack it must not necessarily be broken up, but if stopped with a good stopping mixture, will at least make "Thirds," which will be more profitable than breaking in the biscuit.

In the **Underglaze Printing** department, there are four fruitful sources of error:

Breakage,
Smearing the fresh color, and
Not transferring and properly rubbing the prints.

It is often difficult to say what person or team is responsible for loss, and to facilitate this a good way to do is to give each printing team a stamp with a number on it to place on ware that they handle. It will then be seen at a glance who is responsible, and knowing this it will be a great step towards overcoming the difficulty.

There are many losses which occur in the last stage of the process due to the negligence of kilnmen as well as by accidental losses.

Brown Ware may be caused either by carelessness or accident. It is caused by a sagger breaking open, wads contracting, or the tops and cracks in the sides of the sagger not being properly stopped up. The flame, dust and kiln gases gain access to the sagger in some of the above-mentioned ways and leave a deposit of ash. The ash from coal always contains at least a small percentage of iron, and when this becomes mixed with the glaze, it gives it the characteristic brown color due to this metal.

Aired Ware is caused in just the same way, only there is no ash to deposit. The kiln gases and flame go into the sagger and take away all life and gloss from the glaze, leaving it dry. If the piece of ware has an underglaze pattern, it will stand out in relief and the lines of the pattern can be very distinctly traced with the finger.

Both of these above-mentioned losses can be prevented, at least to a great extent, if care is used by the placers.

Dirty Ware is very common, and in fact one of the worst causes of loss in the final part of the process. Pieces of the wad are a great source of dirt and it gets onto the ware, either by the crumbs of it falling off the kilnmen's hands, or by flying when being fired. This flying is caused by the too rapid expulsion of water vapor which cannot well escape; and the more plastic the material, the more subject it is to this trouble. A wad should be made from a plastic ball clay and contain as much sand as possible and yet be plastic enough for the kilnman to pick up a piece of convenient length. It is well to have a wad rather soft so that it can spread out under the pressure of the sagger on top of it. A clay about as plastic as Tennessee ball clay No. 7 and grog, when made into wads should contain about 22% water.

Some times it happens that bits of top sagger wash peel off and drop while under fire, and these can be identified as little spots usually geometric in shape. The remedy for this cause varies with different washes used, and can

best be found by experiment. The object being to find a mixture having a greater tenacity.

Pin body is often found in the ware when the kilnmen try to make a pin fit a hole that is too small, and as a result the crumbs fall onto the ware, making a number of cream-colored spots close together and located just over the pin mark on the under side. The remedy for this is to see that the sagger punch is the right size, and if so, then examine some saggers that have already been made and find the cause that prevents them from freely entering. Large pieces of the sagger are sometimes found stuck fast to the ware. This breaks off the top generally because the inside of the top forms a sharp edge. This edge should be completely rounded off so it will leave no pieces to crumble off.

Stuck Ware. In case of the ware, such as dishes, being stuck, the cause is frequently that the thimbles used in placing them are too small. The trouble sometimes occurs in bowls that are nested and should a stilt give away the top bowl leans against the next below it and will also stick. Sometimes it happens also that both stilts and pins are the right size, but in carrying a filled sagger from the placing bench up a pair of steps and to the top of a bung, they are subjected to certain jerks which cause them to shift out of position and stick. Correct size stilts and pins, with a reasonable amount of care, should obviate most of the trouble in this line. Many of the defects found in the glaze from this cause can be remedied or helped by touching the spot with a rapidly revolving carborundum, or stone wheel and then polishing with a felt or wooden wheel, containing a little pumice flour on the surface.

Sulphuring. This may be caused either by the fuel used or by the composition of the glaze. If it is caused by the glaze, it is probably due to the presence of some impurity containing a sulphate. If it is due to firing, it must be the fault of the fuel containing too much sulphur, and when not enough air gets through the kiln the gases are more saturated with it, thus causing it to do more

harm than if diluted with air. It is identified by the presence of a scum on the surface which can be washed off with water.

Reducing of Lead is caused by the kiln atmosphere being under reducing condition or containing carbon monoxide. When lead is reduced, it turns black, and for this reason there can be no mistake in its identification. To overcome this, there should be more air admitted to the kiln so as to oxidize these gases.

Breakage is also one of the most fruitful sources of loss, and to obviate this care is the only remedy.

DISCUSSION.

Mr. Simcoe: I would like to suggest to Mr. Mayer another possible solution of the dunting. He claims that a remedy would be to change the body, the change being probably the addition of more plastic clay, is that the idea?

Mr. Mayer: Yes, sir.

Mr. Simcoe: With a body containing 60 percent of ball clay—does your's contain that much?

Mr. Mayer: No.

Mr. Simcoe: I have found this same condition to exist with such a body. You also stated that you found this in the large pieces. That seems to point to a theory that I advanced last year in regard to pug mills, that the structure given it by the pug mill, that is, laminations given it in pugging, possibly is the cause of that dunting following the line of lamination. You also stated, I believe, that it is spiral in form.

Mr. Mayer: Yes, sir.

Mr. Simcoe: Would not that suggest improper pugging?

Mr. Mayer: That spiral form may also be due, in the case of a plate or other giggered article, to a circular impulse given by the gigger, I should think.

Mr. Binns: I question whether we are right in classifying non-plastic material as such, both in the case of

flint and spar. Does Mr. Mayer mean to say that an excess of spar would cause dunting?

Mr. Mayer: I should say that it would if used in large proportions, if you did not have enough ball clay or other plastic material with it to make it into a workable body, it would also tend to cause dunting the same as an excess of flint.

Mr. Binns: I should question that altogether. The dunting takes place after the body has been made and after it is passed through the biscuit fire, and mostly after the subsequent glost fire. You do not often find biscuit dunting, so that the working of the body is not such an important factor.

I believe that we are wrong in thinking of body structure in terms of ball clay or flint or feldspar. We ought to think of it in terms of clay substance, quartz and feldspar. One reason why Mr. Simcoe's ball clay may have caused dunting is that it is not at all uncommon to find ball clay with 25 percent of quartz, and unless this is brought down to the terms of rational composition, you cannot be quite sure what you are doing. In other words, it is quite a mistake to replace kaolin with ball clay until you are perfectly sure that the terms upon which you are working, that is, the terms of clay substance and quartz, are fully understood. I am persuaded from long observation that dunting is in the main due to a too high content of quartz. It is not necessarily the non-plastic material, but the too high content of quartz that causes dunting. It is true a high content of kaolin may contribute in this direction, partly because kaolin may contain quartz. I have known bodies to dunt seriously which had apparently no excess of quartz, but it was almost always found that the quartz was higher in its percentage than was apparent.

Mr. Ashley: I agree thoroughly with Mr. Mayer in his statements that dunting is often caused by a lack of proper bonding material in the body. I have traced it back in quite a good many cases in the following fashion.

A piece of glost ware is found dunted. The dunting will often be found starting in a very fine crack which evidently existed before the piece of ware went into the glost kiln. But it is a crack which, nevertheless, it is almost impossible to detect in the biscuit state. I have seen also a good deal of dunting of very similar character in the biscuit kiln, and this dunting seems to start with a small crack such as is called a "kiln crack" but which I call a "clay shop crack," because in almost every case this can be traced back to the clay shop, and can be found due to the undue strain brought upon the ware in the green state in the clay shop. For example, one time I took six dozen plates and lifted a portion of them one at a time by the rim and put them in the kiln that way. I took another lot and lifted them two at a time by the rim. I took some three at a time by the rim, etc., and I found that I could get all sorts of kiln cracks by that method of handling the green clay ware, and that dunting is one of the characteristic forms in which this ware broke, this ware which I mishandled. It can be mishandled all through the shop, in finishing, in placing on the boards, in bringing down to the kiln, and placing in the saggers. Whenever too much load is brought on it, strains are produced which cannot be seen in the green clay. Some of them are not seen in the fired biscuit. Many of them only appear first after the glaze is put on the ware, that is, just after dipping, as a raised line of extra thick glaze. A larger amount of plastic clay in such cases would make the ware mechanically stronger and better able to stand these handling strains in the clay shop.

Pugging, batting out, and jiggering, as said by Mr. Simcoe and Mr. Mayer, probably determine the shape of the dunt, while the handling strain determines where the dunt shall start.

Mr. Stull: Mr. President, it seems to me that the real cause is due to the peculiar expansion of quartz. A small crack may make a weak spot where the influence of

this expansion will show up. If a piece of ware is under stress, a previous flaw may be the means of throwing it out of equilibrium—thus producing dunting. In my own practical experience I found that it occurred during the cooling. In the neighborhood of 750 to 800 degrees centigrade, during the heating up, there is a partial conversion of quartz to tridamite, which represents a sudden increase in the volume. During the cooling there is a partial reversion again, at the same temperatures in which the tridamite goes back to quartz, which represents a sudden contraction. This sets up a stress which may relieve itself at the weakest point in the ware. I have reduced the flint and stopped it in some cases.

Mr. Stover: I would like to ask Mr. Stull whether he has had any experienec in having ware placed on the floor, being apparently in good shape for a week or ten days, and then find dunting, even stand around and hear it go off? You will find that occasionally in cases where no apparent weakness is found. In such case as that, would it not seem to be due either to the mixture or to the fire rather than the strain?

The proportion of large pieces dunting is something that anyone that makes large pieces cannot doubt. Occasionally it comes where there does not seem to be any legitimate excuse for it. You can turn it over and trace it back to a weak spot, or what would seem to give it a strain, and you will know why you lose that one piece, but that does not enable you to get down to the real cause for each crack.

Have you had any experience, or has anybody considered a relative percentage of coefficient of contraction and expansion between quartz and alumina in this regard? The factor as 8 SiO_2 and 5 of Al_2O_3 would seem, as I understand it, to give a greater contraction and expansion between hot and cold with the alumina in the mix than with the silica. The practical effect in my own experience in this line, is that nearly all these dunts that give us a

nuisance, do not seem to come from any particular reason that you can trace . But after being for several days at a certain temperature, you get them up against a cooler atmosphere and away they go without any apparent cause.

Mr. Binns: Mr. Stover's points on the relative co-efficients of silica and alumina is not comparable to our case, because when you deal with glass you are dealing with silica in a molten form and, in that state, it is well known that its co-efficient disappears almost entirely. Crystaline quartz has an extremely high co-efficient, molten quartz has none or almost none. That is one reason why we can cure crazing by adding quartz, either to the glaze or to the body, being in the one case a crystaline form and in the other case a molten form.

Mr. Thomas: Why is it more susceptible to dunting the closer the grain the piece of ware? The more vitrious it is the more susceptible it is to dunting.

Mr. Mayer: I cannot say, but my idea is that you do not find many more duntings in denser or vitrified bodies than in the lighter or earthenware bodies.

Mr. Stull: It is more susceptible when coarse quartz is used than when fine quartz is used. That has been my experience, anyway.

Mr. Cowan: Mr. Mayer gives as one of the causes of sulphurizing in the kiln, the presence of sulphate in the glaze. I should think the use then of magnesium sulphate, to prevent ropey glaze, would be rather dangerous.

Mr. Mayer: It is added in such small quantities that it hardly affects it. If your glaze does not contain enough of sulphate before that, the small amount that you would add in that case would apparently do no harm. At any rate, it does not do so.

DISTINCTIONS IN THE GRADING OF WHITEWARE IN COMMERCE — PARTICULARLY OF PLUMBER'S WARE.

BY

CHARLES WEELANS, Trenton, N. J.

In introducing the above subject I do so with the full knowledge that among ceramists generally there is little or no doubt as to the proper grading of the different kinds of pottery that usually come under the head of whitewares.

In table ware we have the common earthenware, vitreous earthenware, semi-vitreous earthenware, the porcelains, etc., and the characteristics of each having been clearly defined by various authorities, are probably all well understood.

In sanitary plumbing ware, however, of which we wish more particularly to speak, owing to the introduction of some new compositions or old ones revived, together with improper names having been given to each, their proper classification has become somewhat obscure. In some literature and in various trade advertisements we find the names of "Vitreous Ware," "China Ware," "Vitreous China," "Vitreous Earthenware," "Porcelain," "Vitreous Porcelain," "Solid Porcelain," etc., all given to the one type of ware. This product is expected to answer to one or all of these various names as used in many specifications which have been written during the past few years, and which we have naturally found it difficult to comply with. Therefore, to establish a better understanding of the proper terms to apply to this product is the object of this note, and to facilitate discussion on the subject we will present the various names which have erroneously been given it, explaining our conception of the true mean-

ing of each and by comparison secure for it, if possible, a name both appropriate and easily understood.

Porcelain.

This ware, known as hard porcelain, is understood by ceramists as being among the purest and finest of clay products. Its color is approaching pure white, and it is composed of a hard, dense, translucent body. Being vitreous in character, it comes near to being non-absorbent. It is free from craze when properly manufactured, and inasmuch as it is composed of the purest materials, is among the most beautiful and most durable of pottery.

Vitreous China.

This term is used repeatedly in connection with common ware, and probaby was called into use owing to the name "china" being abused by some manufacturers who, wishing to enhance the value of their product, applied the name "china" even to some of the lowest grades of earthenware. Hence the terms "vitreous china" and "china" are properly identical, the word "vitreous" being added to distinguish it from the lower grades of earthenware, which had assumed the name "china." The word vitreous when used in this connection is, therefore, unnecessary, since it can hardly be considered china except it be vitreous.

Earthenware.

Earthenware is a commoner and cheaper grade of table or other ware. Its color is less white than china, is opaque in character, more or less porous, and probably more subject to craze.

Vitreous Earthenware.

Vitreous earthenware is earthenware vitrified by the application of higher temperature in burning, or a change in the proportions of fluxing elements used in common earthenware, or both. The color is not materially different

from that of earthenware. It has the appearance of a much harder substance than earthenware, which difference can be noted (as well as by other means) by its clear bell-like sound when hit by a metal or other hard instrument. It is, when properly manufactured, probably less subject to craze than common earthenware. It is used for table ware and plumbing goods such as lavatories, closets, sinks, urinals, etc.

Semi-Vitreous.

This ware, called semi-vitreous, is composed of a hard, somewhat close body, but not sufficiently dense to bring about that translucency noticeable in porcelain or vitreous earthenware, nor is it nearly so porous as common earthenware. Its color is similar to vitreous earthenware, being less white than china. When properly manufactured it is probably free from craze. It is not non-absorbent. It is used for table ware and to some extent for plumbing goods, such as closets, urinals, etc.

Heavy Vitreous.

This is a new term, having been but recently used to describe a composition employed in making large sanitary articles. It is composed of a vitreous earthenware body and a certain percentage of previously burned material in the form of finely ground particles. Since previously unburned materials when fired above the temperature necessary to liberate the hydroscopic and chemically combined water contract, their volume is reduced. The previously burned material, however, which is incorporated in this heavy vitreous ware, having already been reduced in volume by previous burning, remains in the second burning practically the same, while the unburned material, through firing, is reduced in volume and is removed more or less through contraction from these minute particles of previously burned material incorporated in the body, leaving a cellular-like structure lacking in the compactness notice-

able in the vitreous earthenware composition. Owing to this cellular like structure the finished product called "extra heavy vitreous" is more highly absorbent than vitreous ware.

Fire Clay Porcelain, sometimes called **Solid Porcelain.**

This product, although called porcelain, differs widely from any of the kinds of pottery above described. Its base is composed of what is commonly called "fire clay." Its body, being made up of fire clays and an admixture of formerly burned material or broken ware, called grog. It is an open body and more or less porous, although subjected to a greater heat than much of the vitreous ware. It is covered with a china engobe, which gives it a fine white color and vitreous surface. While it is sometimes more prone to craze than vitreous earthenware, it should not be looked upon as being unavoidably so, for much of this ware has been known to have great endurance. It is used for heavy plumbing goods such as closets, bath tubs, and other heavy ware.

Solid Vitreous.

This name is also new, but since its composition is identical with that used in heavy vitreous, the name describes the mode of construction rather than the character of its composition.

Webb Vitreous.

This name, like the name "solid vitreous," is explanatory of the particular mode of construction and, therefore, does not indicate any special composition other than the usual one used by manufacturers of large vitreous pieces, although often understood to do so.

All the above described terms have at one time or another been applied to ware similar in character to a product of the following composition:

Spar 900
Flint 900
Florida Clay 600
Goldings 500
English Ball 400
0.2 K_2O Al_2O_3 4.87 SiO_2

of which in a large measure heavy sanitary ware is made. It is burned at different temperatures by different manufacturers, but usually about cone 8 to 10. It is vitreous when properly treated, and its power of absorption is small. It resembles porcelain or china only in its hardness. It is distinguished from common earthenware by its vitreous character and its hardness, color being little different. Since the materials of which it is composed are less carefully selected than those used in making china, it is lacking in the beautiful color and fineness noticeable in the porcelain. The terms "china" or "porcelain" cannot intelligently be applied to it, nor can it rightfully be called common earthenware. Common earthenware lacks vitrification, hence is porous and highly absorbent, which inferior qualities are almost entirely absent in the ware just described. For the same reason we cannot call it "semi-vitreous," for it too lacks the commendable quality of being vitreous and of low absorption.

Since it cannot, in our judgment, be called "porcelain," "china," "earthenware," or "semi-vitreous" ware, there is but one term we may rightfully use in this connection, namely, "Vitreous Earthenware," for the character of vitreous earthenware and the ware we are describing are identical. The color of each differ little, if any. The materials of which they are composed, the proportions of same, the temperature used in firing, and the low absorbing qualities are quite the same. Hence our conclusion that vitreous earthenware of all other terms can be most intelligently used in describing it.

Tests and Specifications.

In many specifications as now written it is demanded that this ware be vitreous and non-absorbent. While the

danger of failing to reach a satisfactory point of vitrification may not be difficult to comprehend, the possibility of attaining a non-absorbent product is not so simple. To go beyond a certain point of vitrification in heavy sanitary ware has been proved dangerous,—dangerous not only to the manufacturer, but in coming in contact with the extreme changes of temperature when in use.

Some specifications, however, demand that all sanitary ware be subjected to the *Red Ink Test* to determine its porosity. This test is particularly severe, inasmuch as it requires a highly vitreous structure to successfully pass same, which structure invites the much feared condition of cracking when in use. A more moderate test would, therefore, be not only as effective but result in a more satisfactory product,—more satisfactory to the manufacturer inasmuch as the loss would be lessened, and to the user as the liability to fracture when in use woud be much less. The manufacturer, having constantly in view the severe test applied to his ware bends every effort to attain a highly vitreous product, and in doing so inevitably increases the liability to over-firing, which frequently brings about the above described dangers. Since durability and sanitary perfectness are not dependent upon that height of vitrification necessary to successfully meet this red ink test, and since the efforts of ceramic manufacturers to obtain this condition inevitably leads to the greater danger of defective product, why employ it? Other clay products such as vitreous paving bricks, etc., are acceptable after a much less severe test. The best paving bricks are required to be of a vitreous character, but beyond a certain point of vitrification, which is much below that necessary to meet the red ink test successfully, it is considered dangerous to go. To reach a high point in vitrification makes the product too brittle to be durable; hence the water test is given, and the product which absorbs not more than a certain small percentage of water is considered satisfactory. The same conditions obtain with pottery, although the

different products are used for widely different purposes. The conditions of manufacture that render vitreous bricks too brittle to be durable are in part the identical conditions that bring about this fault in pottery, namely, high vitrification, and in the judgment of the writer it should not only not be required but should be avoided by making acceptable a lower point of vitrification, and, in order to determine such point, a more moderate test than the red ink test.

A second test is that applied to the glaze, namely, the glaze must resist *Scratching with Steel.* With reference to scratching the glaze with a steel, it might be said that it is highly questionable whether there is any glaze usable in heavy pottery which could successfully pass this test. It is extremely difficult, if not impossible, to secure a glaze for large pottery that cannot be scratched more or less with steel, and the extent to which it may be scratched is dependent upon the pressure used upon the steel when testing and upon the hardness of the steel. Since different pressures give different results, and at present no testing machine for this purpose that is entirely reliable is known, the liability for error is apparent. Its results could, therefore, hardly be other than unsatisfactory and misleading.

Next is the *Metal Pipe Test.* With reference to the use of a metal bar for strength testing it may be said that this test too, in the writer's judgment, since it cannot be other than unfair, is unsatisfactory and inadequate. In no test yet mentioned is the liability to error greater than in this test. The breaking of a piece of ware is not only dependent upon the instrument used and the power of the impact, but upon the position or part of the ware upon which the impact is made. A piece of ware might successfully stand a dozen blows if hit in one place, while it might be shattered to pieces by one blow if hit in other places. Again, unless some reliable testing machine that could be expected to give an even strength of blow be used, the test

mentioned could hardly be depended upon to give anything like reliable data as to the impact-resisting ability of any ceramic product.

There are other conditions not mentioned, such as the different modes of construction used by different manufacturers in making the same pieces of ware, which fact would result in the different pieces of ware having their greatest impact-resisting power distributed in different points. This fact would, in case of pieces of ware being tested at the same point give varying results, while if all the pieces were broken at all points they might be considered equal in strength.

Other like illustrations of the unfairness and inadequacy of this test might be given if necessary. It is the judgment of the writer that where a test of this kind is required it were better to use the rattler or impact test. The rattler is made by selecting a lot of broken pieces of ware, weighing same carefully, and placing them in the testing machine for a given period of time, after which they are again weighed and the loss noted.

The impact test is carried on by a reliable impact testing machine, namely, by selecting a number of pieces approximately the same length, width and thickness, and noting the number of blows of a given strength required before breaking them.

These are all simple tests, their principal feature being their comparative reliability, and in the judgment of the writer should be employed wherever possible in preference to unfair and unsatisfactory tests mentioned above.

DISCUSSION.

Mr. Stover: I think we are in somewhat the same shape with this as with the question of materials. When we are buying materials we want to know whether we are getting the material we are supposed to be buying. And a good many of the customers in the sanitary line are reaching that same point, that they want to know the different

kinds and classes and how close they are getting to reaching the standard that they are paying for. Presumably some of the government officers have decided to try to establish a set of standards to be reached by the different manufacturers.

Mr. Weelans: I would like to ask if any one of the members have a method of determining the porosity of a pottery body, especially vitreous earthenware.

Mr. Orton: A great many determinations of the porosity have been made on pottery wares and clay wares, but I do not think there is any approach to a standard method. Some would select larger and better glazed test-pieces, with less crazing of the glaze, than others, and the consequent results would not be very closely comparable. I think standardization of the absorption test is necessary for pottery, just as much as for paving brick or any other ware.

The points brought out by the paper indicate that either this society or some other organization ought to step in now, and try to devise some standards which will define the different classes of whitewares. It does not appear to me as a particularly difficult matter to define the proper groups of whitewares, but it will be one of those investigations in which the amount of detail is very great, and the amount of painstaking labor will be considerable in order to define the standards properly.

A good deal of work has been done on standardizing paving brick tests, both the rattler tests and other tests, but even on the rattler test alone there was room for an endless amount of investigation, to run down all the possible modifications and prove what is absolutely the best way to do. And even now, people disagree as to the results of the rattler tests. In tests, more or less subject to slight variations in the procedure, variations which the operators themselves oftentimes think unimportant, the cumulative effect is enough to make two operators unable

to check each other when they think they are doing exactly the same thing.

If this society could appoint a committee, or better still a committee would volunteer to take up this work of standardizing the different grades of whiteware, it would do the country a great service, and give prominence to this organization at a time when it will do it some good. There is going to be more careful grading of ceramic products in the future, and I think now is the psychological moment for such a committee to get to work. But, of course, it should be understood that whoever attempts to do a piece of work like that, will find almost an endless amount of labor involved. I do not think any committee which would be appointed would be apt to produce the needed results, any more than most of the other committees that we have now outstanding are producing results. But if there are enough men here really interested in this matter, and who will be willing to volunteer for this work, it will not be beyond the power of such a body to produce a reasonably good set of standards in another year.

Mr. Weelans: I would say in further explanation of our interest in this question that certain specifications designate that all plumber's vitreous ware is required to successfully pass the ink test for absorption, the pipe test to determine strength, and the steel scratching test to determine the hardness of the glaze. To decide as to whether ware is satisfactory, one of the articles of a given shipment is broken and the ink applied. If the first piece of ware tested fails to pass same, another piece of the same shipment is broken, and in case of failure a third piece is tested. Should all fail, the whole shipment is returned to the manufacturer, who must stand all expense of the ware broken for the test as well as all freight charges, etc. If, however, any of the three pieces successfully passes the ink test, all expense of the broken pieces tested is borne by the purchaser and the goods accepted. All ware here spoken of is large, expensive pieces of plumber's ware.

It is evident that in the manufacture of a vast number of these pieces it is not always possible to treat each piece satisfactorily, that some come from the kilns less able to withstand this test than others, and should any of these pieces be chosen for a test of this character a failure may result, while in reality the shipment as a whole would be as good from the standpoint of vitrification and other points of merit as any other shipment which might be accepted.

It was the writer's thought that no authority was nearly so satisfactory to decide the merits of these various tests as the American Ceramic Society. It is important to many manufacturers of this class of ware, in Trenton and elsewhere, to have a more satisfactory and practical test to decide the merits of the ware on the points herein mentioned, and to secure better methods than are now in vogue, since these methods are unreliable and unsatisfactory.

Mr. Stover: In regard to Professor Orton's suggestion that somebody volunteer, I do not believe that Mr. Weelans would require very much persuasion to agree to go into a job of that size without assistance. But as we are both in Trenton, if he will undertake to be chairman of that committee, I will be another one of the committee to help, but I would like to have some suggestions from some of you gentlemen that have done work along that line. Mr. Mayer had in his paper the results of the rattler test and the absorption test and two or three other tests of that kind, and if any others have them and we can get hold of them, we can use them. There is a paper on standard tests of paving brick, by Professor Orton. I do not remember what absorption test was finally settled on.

Mr. Orton: The absorption tests were practically thrown out. The specifications of the National Brick Manufacturers' Association make it optional whether absorption tests should be used at all. They pin their faith on an abrasion or impact test, made in the rattler, and think that a ware which will resist that test does not need any endorsement from the absorption test.

Mr. Stover: But many bricks that would pass that test are liable to a very wide variation in absorption.

Mr. Orton: Yes, that is true. One or two papers have been written on that subject some time ago, in which the evidence tended to show that any brick which would pass a rattler test safely would also be safe from the dangers resulting from too much absorption. That is to say, the bricks would not absorb enough water to go to pieces by frost, if they were hard burnt enough to pass the standard rattler test.

Mr. Stover: Did you ever ascertain the maximum amount of water a brick might take without becoming liable to damage by frost?

Mr. Orton: That is a function of the clay. No single percentage can be laid down. That was the one reason why the absorption test for paving brick was rejected by the N. B. M. A., because it was found that different clays have an individuality about the matter, and one may stand three or four times as much water as another, when subjected to frost. Some are only safe while they are below two per cent, while others will safely stand 6 or 8 percent.

Mr. Stover: Did you fix a two per cent figure?

Mr. Orton: No, I never did, but the two per cent limit has been in somewhat common use among city engineers and others that test paving brick. Of course you will find some specifying one percent, and some three per cent, and so on. There is no standard adopted by the American Society for Testing Materials, or by the National Brickmaker's Association, specifying how much water a paving brick may take and still be considered good.

Mr. Stover: We can all see how much easier it would be for an absorption test. All they would have to do would be to put a number of bricks in a solution for a given length of time, but when you demand that they pass a rattler test, you have to get a machine. That is exactly true of this very line of ware Mr. Welans was talking about. They get a red ink test, and when I tell you that from actual

observations of my own I found in one piece of ware after soaking ten days, six one-hundredths of one per cent on one part of the piece and one and one-half per cent on the other, you can see what an absolutely queer kind of standard you set, either for the government or for anybody else by the red ink test. There was that difference in the two ends of a sanitary piece not 16 inches long. That is one of the reasons why I believe that it is a very important thing for this society to handle. If we can fix this standard right we will do a service to everybody in the business. If the rest of you gentlemen who have done work in this line will give us the material to work with, Mr. Weelans and I will try to bring up something here.

Mr. Orton: Quite a few years ago, a number of my students were studying the impact or abrasion test as a means of determining the toughness and strength of clay wares in general. It was assigned as a sort of a problem, that different groups of students were to devise a mode of applying this test to different classes of wares. Some of them had to test vitreous floor tiles and others had floor tiles that were not vitreous, and others had pieces of paving brick, and others had pieces of sewer pipe, and one group had pieces of porcelain dishes to test. Each went at it in their own way, to devise such conditions as seemed to give a test of rational severity for their kind of ware.

In testing porcelain plates, a half dozen samples of a standard American make of hotel china, and a half dozen of the same grade of French manufacture were taken. The two brands were competing for exactly the same business in this country.

We cut those plates up into pieces substantially one inch square. They were calipered for thickness, and found to agree within three one-hundredths of an inch, so there was no substantial difference. These were soaked in water 48 hours. Perhaps they were heated first, in order to expel all moisture from the surface and interior, and then soaked in water. Finally, they were brought from the water and

rapidly wiped dry and weighed again. The absorption of each brand was small indeed. There was no important difference between the two samples in this respect.

The two samples were then put into a ball mill with a small amount of flint and porcelain pebbles about the size of hickory nuts, and subjected to a rattling test. The American ware came through that test very much better indeed; in fact, it lost only about one-third what the French ware lost. The difference lay in the degree of brittleness of the two bodies. On the other hand, if the test had been on the question of translucency, the French ware would have had much the best of it. This case simply represents an effort by students to apply the rattler test to pottery, but at the same time it seems to me that it offers a rational basis of comparison of the relative toughness of our ware, a factor which I should think would be a matter of a good deal of importance to those dealing in hotel and restaurant goods. The absorption test failed to develop anything, but the rattler test immediately developed something of tangible importance.

Mr. Cannan: There is no question when the rattler test is used in testing china which ware will stand the best, —it is always the American china. This is due to the difference in processes used. The process used by the French in the manufacture of china gives a body of glassy fracture, while the process used in this country gives a rock fracture; for this reason ware from this process is much stronger and more serviceable. It is claimed that the French ware has a better glaze than the American ware,—there is a question about this. The French body not being as strong as the American the ware does not stay in service so long. We believe that when the quantity of ware used and the length of time in service are made factors in judging the glaze, the American ware stands ahead of the French. It takes about six days in a test to differentiate between glazes. I believe it is true that the French has the best of the American when body color is considered. The red

ink test is a hard one, and there is a question whether it should be applied.

Mr. Stover: One test of hotel ware we meet pretty much all over the country. They will tell you pretty quick that they want a ware that will go through the washer and not chip; therefore, they do not care how you make it or where it comes from, if you give them the ware that they can actually put into service and run through the dish-washer without chipping.

In regard to the scratching, wouldn't that be a good test anyway? That is, to take two plates and put one between the same make and apply a slight motion, and let it run with a little water and something to abrade it. If it is a very fine glaze and you let it run for two or three hours, you will find that that will tell you mighty quick about the durability of your glaze. That is a method, I think, employed on some of the French specimens and on some of the glazes that are now being made.

Mr. Cannan: The real test is how the glaze will wear in the apparatus used for washing the dishes in hotels. As said before, the length of time the ware is in service is a factor.

Mr. Stover: That is all right, give a certain rate of speed and a certain length of stroke, so that they will all be treated exactly alike, and then compare results.

Mr. Orton: Mr. Cannan, how do you make this six-day glaze comparison?

Mr. Cannan: In a tumbler in which the plates are fastened and held securely, and a quantity of given sized particles are put in and the tumbler rotated.

Mr. Orton: Two kinds of plates are fastened rigidly in the rattler?

Mr. Cannan: As many different kinds of plates as the tumbler will hold.

It is best to test ware with fragments of similar ware. Probably Mr. Mayer has some experience in this line. The American hotel china, they say, does not show up as well

on the table as the French and German wares, and in some cases we must grant that is so, but here again the length of time in service is a factor. If a piece of ware is in service only six months, naturally the glaze will not be worn and marred as the glaze on a piece of ware that has been in service five or six years. Many plates of the best American china have been in service for five or six years.

Mr. Ernest Mayer: I do not know of any satisfactory tests developed so far in reference to the glaze. Any test I have made has been in connection strictly with the rattler, and referred to the body. I use cubes of different bodies. I think Mr. Cannan brought out a point in regard to the toughness of American vitrified china that is correct. There is a lot of so-called vitrified ware made in England, but the only vitrification about it is the stamp on the ware. This ware is no more vitreous than the bulk of the semi-porcelain ware made in this country; it is all more or less absorbent. I am speaking of American vitrified china, and that stands in a class by itself. Of the toughness of the ware as compared with anything made in France or Germany, there is no comparison. It will outlast them all many times. As far as any satisfactory glaze test is concerned, I do not know of any.

THE CONTRACTION OF GLAZES AND GLASSES ON SOLIDIFYING, AS A CAUSE OF CRAZING.

BY

H. F. STALEY, Columbus, O.

It has long been customary to attribute all crazing to the glaze having a higher coefficient of thermal expansion than the body. Seger accepted this view and furthermore, among his well known rules, makes the statement that crazing can be reduced by substituting for a fluxing material with a high equivalent weight an equivalent amount of one with a lower equivalent weight.

Ever since the publication by Hovestadt of the results of the exact measurement of the thermal properties of glass made at Jena, it has been known that they do not agree with Seger's rules. The relative influence of equal molecular portions on the coefficient of expansion, beginning with the one giving the highest coefficient, are shown in Column I. Column II shows the fluxing materials arranged in order of their molecular weight, which is, according to Seger, the order in which they increase coefficient of expansion when used in equal molecular proportion:

I.	II.
K_2O	PbO
PbO	BaO
Na_2O	K_2O
BaO	ZnO
CaO	B_2O_3
ZnO	Na_2O
B_2O_3	CaO
MgO	MgO

It will be noticed that I have placed B_2O_3 among the fluxing materials. This is not according to Seger, but it certainly acts as a flux in glazes and glasses of normal composition. As shown by several members of our own society, it has a moderate tendency toward producing

crazing, probably corresponding to the place assigned to it in Column II. In my own experience, I have used large amounts of B_2O_3 with uniform success, on this supposition.

Now if crazing is caused by high coefficient of contraction, we should be able to reduce it by replacing part of any fluxing material in Column I by an equivalent amount of any one occurring below it. By so doing we would, in many cases, be going contrary to Seger's law, yet to the best of our knowledge be reducing the coefficient of contraction of the glaze. Now the disconcerting thing is that working with Column II we can stop crazing, while with Column I we are liable to increase it. Instances of this would be if we were to replace Na_2O by BaO, or CaO by ZnO; and all the while crazing is supposed to be stopped by reducing the coefficient of expansion.

Considerations such as the above led me to take a theoretical, as well as a very practical interest in the phenomena of crazing.

I was engaged for several years in the manufacture of enameled iron sanitary ware. Like thousands of others, I followed Seger, and corrected any tendency toward crazing by using the list of fluxes as given in Column II, and replacing one high in the list by a molecularly equivalent amount of one lower down. As long as I kept within the allowable limits of normal enamels, the plan worked well.

Owing to the nature of the ware we were manufacturing, it was possible to observe it closely at all stages. This was especially true of the cooling process for, as you know, a piece of enameled iron is simply set aside to cool in the open room, or at the most, run into a cooling shed to keep it out of drafts of cold air.

As it cools down the iron loses its redness and the enamel becomes more and more viscous. Just as the enamel is changing from a very viscous fluid to solid glass, a series of sharp crackling sounds are heard for a period of from three to five minutes. If these are especially

loud, the piece will be found to be crazed when it is cool enough to examine. Any boy "helper" in an enameling room can tell by the "crack" of a hot piece whether it will be crazed or not. It is quite possible to see large crazes open before your very eyes. In this connection, it is of interest to note that thousands of (some experienced men say all) pieces of enameled iron show faint crazes at this stage, which have entirely closed up by the time the ware has cooled to atmospheric temperatures. If a piece of enameled iron does not crack loudly, and does not show crazes when cool, the chances are several thousands to one that it will never craze. It was my duty to inspect some 200,000 pieces of sanitary enameled iron as they were made, and also to keep record of all pieces that subsequently proved defective. I never saw a case of crazing that seemed to have developed after the ware became cold. It is axiomatic among manufacturers of this class of goods that if they are not crazed when inspected on being taken from the enameling room, they will never craze.

There are several measurements of the contraction of glass on solidifying. Barus[1] determined that liquid basalt contracts 3½% to 4%. Mallet[2] observed that plate glass (taken as an example of an acid silicate) contracts 1.59%, and that iron slags (basic in composition) contract 6.7%. The familiar dishing of a fritt that has been allowed to cool in a crucible is a case in point. In general the higher the silica percentage, the less the contraction. This is the foundation of Seger's law.

The question has often come into the mind of the writer whether this crazing was not caused by the contraction of the glass on solidifying. The invariable relation between the period of solidification and crazing tends to lead one to this view. Of course the fact that the coeffi-

[1] **Barus**—High Temperature Work in Igneous Fusion and Ebulition. Bulletin 103, U. S. G. S.

[2] Proceedings Royal Society XII, page 328. Also **Geike**—Text Book of Geology I, page 408.

cient of glasses increases with temperature, as does also their brittleness, might account for a special tendency to craze at high temperatures. But then this should be stopped by changing the coefficient of contraction of the glass, according to the measurements given by Hovestadt, and this in many cases we can not do.

Now if this crazing cannot be lessened by lowering the coefficient of contraction of the glass, it certainly is not due to high thermal coefficient. If it is due to contraction of the glass on solidification, as the evidence seems to establish, and is cured in all cases by Seger's rules, then these are rules for lowering the contraction of glass on solidifying rather than for lowering the coefficient of contraction of the glass in solid state. The practical use of these rules remains the same, but there arises the question whether the interpretation of the phenomena of crazing and its cure has not been at fault in many cases.

DISCUSSION.

Mr. Shaw: I have had no experience in cast iron. But I performed some experiments on sheet steel, and in the sheet steel enamel industry it is very rare that crazing is had before the sheets are black, in fact it is very rare that that ware ever crazes, although it is easily caused to do so by proper changes in the composition of the enamel.

There is another phenomenon which we know as shivering. I am not sure what it is, but nevertheless I produced those two results, what I call crazing and shivering, in the manipulation of the enamel in the same way as the potters would manipulate glazes to produce crazing and shivering, therefore I call this other phenomenon shivering. Crazing in cast iron, as I understand it, is quite common. We know that cast iron enamels are, as a rule, about four times as heavy as sheet steel enamel, and Mr. Staley has said, if I got his meaning right, that he thought it was possible that this crazing was due to a property of the glaze itself or to its manipulation, rather than to the

relation of the coefficient of expansion of the glaze to the iron, and I think the thickness of cast iron enamel will give some explanation of that effect. Cast iron enamels being very heavy they do develop crazing, but the sheet steel enamels are very light, necessarily so, and they very rarely develop crazing at the factory in any way. Some times, after they are used a while, they develop crazing, but it is not common. Shivering is quite common.

Mr. Frink: What is the temperature at which you noticed this crazing or that you had that cracking?

Mr. Staley: Just as the iron turned from red to black. If I remember right it is probably between three or four hundred centigrade. That is about the same point that glass has to be annealed. If glass is cooled below that temperature without annealing and allowing these strains, set up in it by cooling, to work themselves out, the glass will break. Really I think that crazing is caused in the same way that a piece of glass that is not annealed properly is caused to break. Of course, the practical effect of this, if it holds true, would be that a man should be very careful about cooling his ware too fast. That is, he could cool as rapidly as he wanted to down to the point where the glass is going to solidify, and then he should cool slowly and allow the strains to work out.

Mr. Frink: I was just coming to the point of some experiments that I conducted in relation to glass baits for drawing glass and drawing cylinders. It is quite a problem with us, to find an iron or metal of such relative coefficient of contraction as to permit of glass adhering to it long enough to draw a full length cylinder. But subsequently we developed a means of very slowly allowing that glass to cool, and we found that the cooling might progress down to 370 degrees centigrade before we would get a complete rupture, and in previous instances when we got down to 300 degrees we would get that rupture. Now, that corroborates your experience.

REPLY TO MR. FRINK'S PAPER "FALLACIES AND FACTS PERTAINING TO GLASS MANUFACTURE."[1]

BY

F. GELSTHARP, Lock No. 4, Pa.

Sand. For plate glass factories sand is usually weighed in the dry state, not wet, as stated by Mr. Frink.

Limestone. I have found that if the magnesia content does not vary considerably, it is not detrimental; but large variations of magnesia affects the uniformity of the glass, especially when cullet has to be melted with the batch.

According to my experiments, I find that magnesia compared to lime in chemical equivalent proportions produces a glass which is not so fluid under equal conditions. But when compared weight for weight there is little difference in the fusibility.

Soda. Plate glass made from ammonia soda ash, without any addition of saltcake, is more often reamy and more difficult to free from fine seed than when saltcake is added, or when saltcake alone is used. I believe I have the reason for this: The reaction between soda ash, limestone and sand takes place at about 1040°C and is finished at 1200°C. The mass at this stage is a mixture of silicate of soda and lime, with a large quantity of free sand in suspension. This free sand is gradually being dissolved by the silicate of soda, and ultimately glass is produced full of fine gas bubbles and ream, due to the dissolving of the excess sand, the solution of which is very imperfectly mixed with the mass of the glass. To discharge the seed and dissipate the ream the glass must be raised to a very

[1] Trans. Am. Cer. Soc., Vol. XI.

liquid state for a considerable time, and owing to the fact that at this high temperature there is great danger of the glass pots collapsing, we often find that the heat is shut off before the glass is made perfect, in order to save the pots.

Now, by the addition of a certain amount of saltcake to a soda ash batch a new reaction is caused to take place in the melt when the temperature rises to about 1310°C—the free saltcake is decomposed by the free sand—and this reaction appears to be very energetic at 1370°C. The fine seed from the first reaction is collected together by the new generation of gas, and a healthy boil is produced which gives motion to the metal, thoroughly mixing it so as to dissipate the reaminess caused by the dissolving of the free sand.

The reaction of the saltcake and sand is not really complete although the reaction stops at about 1370°C, for I always find a considerable amount of sulphuric anhydride in glass made from materials containing sulphate of soda; and by raising the temperature much higher a further generation of gas takes place, but this may be actual volatilization of sulphate of soda.

The presence of this saltcake in the finished glass possibly accounts for some of the variations in Mr. Frink's strength tests, and may also in some way account for the property of saltcake glass retaining impressions more than soda ash glass, as there seems to be no other difference in the composition of the two kinds of glass.

I very much appreciate the endeavors of Mr. Frink to have more interest taken in the chemical side of glass manufacture. It has certainly been sadly neglected in the past.

REPLY TO MR. FRINK'S PAPER "ALUMINA IN GLASS."[1]

BY

F. GELSTHARP, Lock No. 4, Pa.

How can alumina in the form of kaolin help to combine the soda, lime and silica during the melting of glass. The ordinary general reactions which take place are:

$$Na_2CO_3+2\,SiO_2 = Na_2\,0.2\,SiO_2+CO_2$$
$$2\,Na_2SO_4+4\,SiO_2+C = 2(Na_2\,0.2\,SiO_2)+2\,SO_2+CO_2$$
$$\mathbf{CaCO_3+2\,SiO_2 = CaO\,.2\,SiO_2+CO_2}$$
$$Na_2SO_4+2\,SiO_2 = Na_2\,0.2\,SiO_2+SO_2+O$$

And as we have always an excess of silica present I fail to see why there should be any reaction between the soda and lime and kaolin, such as the following, which would no doubt take place if there was a deficiency of silica:

$$Al_2O_3:\ 2\,SiO_2+2\,CaCO_3 = CaO:Al_2O_3+CaO:2\,SiO_2+2\,CO_2$$
$$Al_2O_3:\ 2\,SiO_2+3\,CaCO_3 = 3\,CaO:Al_2O_3\,2\,SiO_2+3\,CO_2$$
$$Al_2O_3:\ 2\,SiO_2+2\,Na_2CO_3 = Na_2O:Al_2O_3+Na_2O:2\,SiO_2+2\,CO_2$$

But according to the heat equations these reactions would not take place till after the reactions between the soda, lime and silica were complete:

$$2\,SiO_2+CaCO_3 = CaO:2\,SiO_2+CO_2$$
$$-(360{,}000+273{,}850) = +(509{,}350+97{,}200) = -27{,}300$$
$$2\,SiO_2+Na_2CO_3 = Na_2O:2\,SiO_2+CO_2$$
$$-(360{,}000+273{,}700) = +(506{,}100+97{,}200) = -30{,}400$$
$$Al_2O_3\,2\,SiO_2+2\,CaCO_3 = CaO:2\,SiO_2+CaO:Al_2O_3+2\,CO_2$$
$$-(767{,}500+547{,}700) = +(509{,}350+524{,}550+194{,}400) = -87{,}000$$

According to the foregoing, what we have in the melted mass is a mixture of silicate of soda, lime, alumina and silica.

The silicates of lime and alumina are opaque, and to produce transparent glass these must be dissolved in the transparent silicate of soda. The silicate of alumina has simply been dissolved in the mass, therefore if any benefit has been derived from the addition of kaolin, it could only

[1] Trans. Am. Cer. Soc., Vol. XI.

be owing to a lowering of the temperature of fusibility; but I found by experiment the contrary to be the case—the addition of alumina decreased the fusibility.

Glass containing alumina may be harder or stronger, and possibly a little more brilliant; but in good plate glass these properties are sufficiently well developed.

According to Mr. Frink the presence of 3 to 4% of alumina makes the glass less susceptible to the reducing action of the fire gases. Chemically I cannot see how this could be so, unless it were that the alumina was substituded for soda, thereby reducing the percent of soda and consequently the activity of the glass towards reducing gases, but it would not be possible to do this without making the glass more difficult to melt and fire. It is very doubtful whether carbide of sodium is formed on the surface of the glass in a tank, and if it were it is not an unpreventable evil, as perfect combustion prevents this, and it is therefore not necessary to add anything to the glass in the hope of preventing it.

As most clays associated with sand rock contain considerable iron impurity, it is necessary to wash all sands which contain such clays, or otherwise dark colored glass would result. But of course there are cases where color is not so important, and the associated clay would not be harmful.

My remarks are from the plate glass manufacturer's point of view; and for his purpose I feel justified in advocating purity of materials and properly proportioned batch.

DISCUSSION.[1]

Mr. Frink: I regret that Mr. Gelstharp is not here, so that we could enter more fully into the discussion of his criticisms of my papers.

In the first place, in regard to the existence of sulphate of any character in a finished glass, I have yet to

[1] Following the reading by the Secretary of the two papers of Mr. Gelstharp.

find a method that will detect it, that is, to any extent. This is something that I have looked for for the last three years. I have found, as I said yesterday, traces of what might be sulphate, but it may have come from error in analysis as much as from the glass.

Another point in regard to the addition of sulphate of soda or salt cake to a pot of soda-ash glass, the soda made by the ammonia process, would say that I have not had much experience in this, and I cannot state as broadly as I would like, without his being here to contradict me, my own opinion, but my own opinion is that the addition of salt cake is beneficial, due to what we usually term the after-boiling. What is the cause of that after-boil is the liberation of that very sulphate, and if you do not melt your glass you might then find your sulphate there, in the form of minute seeds or blisters. I have some samples with me that if I had a microscope I could show you—you could not detect them with the eye, but put it under the microscope and magnify it 50 to 75 diameters, and you find the seeds about one thirtysecond of an inch long. In that case you might find sulphate, I cannot say, but I believe salt cake is beneficial then.

In regard to alumina, I appreciate Mr. Gelstharp's discussion as entirely from the plate glass standpoint, and I agree with him that alumina in plate glass might make a difficult melting batch, if it replaced soda, but such is not the case, nor do we add alumina in the form of kaolin. When we buy sand that contains three or four per cent of alumina it is usually there in what I assume colloidal condition, and if you melt soda with the sand and alumina you will find that alumina will go into solution, and you will not find it in the form of stone. Alumina does not rob the soda of its activity towards silica, and it does not combine with the silica. It acts as a neutral agent between soda and silica, and between lime and silica. It goes into the form of aluminate of soda perhaps. We made a product of alumina from shale, underlying a coal bed, by fritting the shale with limestone and salt by

briquetting it, putting it into a down draft kiln, and during firing admitting steam and then grinding it up again, leaching it with water and passing CO_2 through the solution. We precipitated the alumina and formed a carbonate of sodium, showing that soda aluminate will separate from silica under those conditions very easily, and that it is not very closely combined. I believe this is the case in glass, and that is what accounts for the high tenacity we get from alumina.

Mr. Staley: I did not follow that last.

Mr. Frink: What I have described is what is known as the Keyser process. In the first place we took the shale, and this is ground and mixed with salt, common salt. This is then made into briquetts and packed into the kiln and heat and steam applied, which made a sort of fritt of it. Hydrochloric acid was evolved in enormous quantity, and the idea was to produce that as a by-product. This fritt was then taken and ground up and leached. That is, water was passed through, dissolving out the aluminate of soda which is soluble in water; then the residue made an excellent material for cement.

Mr. Silverman: Are you sure that you had aluminate of soda?

Mr. Frink: Positively, because we leached it with ordinary water. We passed CO_2 through the water and when we burned the lime drove off CO_2, which was passed through this solution, and which precipitated the alumina and formed sodium carbonate, the alumina being precipitated as aluminum hydroxide, or gelatinous alumina, which was then filtered out. This is what the process was supposed to do. They spent about $200,000 for a plant, but it was found impracticable.

Mr. Silverman: I do not know that I can say very much on this matter. It deals especially with plate glass. In our work we never employed a sulphate of soda. We used the soda ash entirely, so I really had no occasion to make comparison of the two methods. We experienced

very little difficulty with soda ash, however, in the manufacture of flint glass. So with this problem I am entirely unfamiliar from the practical side.

There is one point about the sodium aluminate when you study the water solution. There are many compounds which can be produced in the dry way that are impossible in the wet way, such as the sulphides of aluminum and chromium. The formation of the sodium aluminate in solution is, of course, carried on in the cold. The moment you apply heat you have hydrolysis, and precipitation of the aluminum hydroxide. I was wondering whether the formation of the aluminate in the dry way might be similar to the formation of the sulphides, or whether the existence of sodium aluminate and potassium aluminate in glass is purely hypothetical. Have you any very good proof that they do exist as aluminates?

Mr. Frink: As far as the existence of the various silicates in combinations in any piece of glass is concerned, I do not believe anybody can go to work and pick up silicate of lime or silicate of lime and soda or any other combination. The nearest I have ever got to it is by etching. In making etchings on the glass sometimes I imagine I find these different silicates, but whether they are or not I have as yet no way to prove.

Mr. Orton: What do you think about the presence of SO_3 in this, Professor Silverman?

Mr. Silverman: There is another point on which I have had absolutely no experience in glass. To be frank, I have never looked for it. I suppose if we think about a substance long enough we can almost imagine it present, and if we are firmly convinced of its absence we may not be so much interested in looking for it. That has happened to analytical chemists time and again. In fact, not long ago we had occasion at a meeting of the chemical society to show a lot of analyses of slag and limestone, and the variety of results obtained by 35 or 40 chemists was almost alarming. It depends upon personal manipu-

lation and point of view. There is a point, however, that can hardly be questioned, and that is precipitation of the SO_3 by barium chloride solution. If you then treat your substance with hydrochloric acid you cannot lose any sulphates that are present. If there is any danger of losing SO_3 which might be confined, you might add a fluoride before you treat with hydrochloric acid.

Another point regarding this formation of aluminate. There seems to be little question that sodium and potassium aluminates are soluble in cold water, and it seems to me that if the glass were ground to a very fine powder and leached, these aluminates would be dissolved.

Mr. Frink: By referring to my last paper you will note in the table tests that were made to get the solubility, and how that solubility was determined, and you will find the percentage of what was dissolved very low, but the soda runs high in the solution. The alumina I must confess, I have never looked for. That is a new thought to me. It has never occurred to me in that connection, and I will try this.

There is another point on which I would like to ask Professor Silverman's opinion. In speaking of the analysis of glass by hydrofluoric acid and stating there is no chance of losing any sulphate thereby, how would you dispose of your silica chloride and fluoride compound, without using sulphuric acid?

Mr. Silverman: You might possibly be able to drive them out by the use of another acid. I cannot answer you definitely, but it seems to me that your chloride might be decomposed without sulphuric acid. If you fuse your glass with alkali carbonates you have sufficient alkali to take up any sulphate that is contained or any SO_3, and the temperature of the fusion would hardly be sufficient to decompose any sulphate formed.

Mr. Frink: I have also used the Smith method, the decomposition of glass with ammonium chloride and calcium carbonates.

Mr. Takahashi: About using wet sand, I do not remember what statement Mr. Frink made last year, but I know it is done. Damp sand, I suppose, applies to crushed sand rock, the dampness of which comes from the dampness of the natural rock. I know a mixer who adheres to use of wet sand, and when he cannot get a damp sand he pours water on the sand. Some claim that dampening sand makes a better mix, but I do not see any advantage except it prevents the dust of the soda and lime flying into the air and making it very disagreeable for men to work. Also it will help to prevent dusting off during charging. Of course, adding water takes more fuel during heating up, but I found that the cost of the extra fuel required is rather insignificant in ordinary cases.

About the magnesia, I never had any particular test made, so I could not say definitely, but I agree with Mr. Gelstharp that the difficulty comes from the variation of the composition rather than from the fact of the presence of magnesia. I think we can use high magnesia satisfactorily if we give sufficient heat to melt it, provided its amount is sufficiently constant.

Mr. Frink: I think in regard to magnesia that Mr. Gelstharp and Mr. Takahashi have mistaken what I have said in my paper, that it was only variations of magnesia content that caused trouble.

Mr. Staley: I have seen them pour water on the sand, though I saw you all smile when he said that, but it is not any joke. In the first place working with anything like soda ash entails a lot of discomfort to the workmen, but not only that, in making up your batches I have found that it pays in dollars and cents to wet down the batch before it is put into the furnace, because the mechanical loss of dust from the batch is so large that it amounts in a 1500 lb. batch to about 60 or 70 pounds, which would be about three or four dollars, so it pays me to put on perhaps about four buckets of water and dampen that down rather than to lose so much dust.

Mr. Frink: There is another reason for wetting the batch that has not been mentioned, which might be of interest to some of you, and that is when you wet a batch it keeps closer together when you dump it on the pile, it does not spread out, and it makes a very close melting batch.

Mr. Binns: I want to make one point in connection with the use of alumina. Mr. Frink mentioned the alumina in the sand, and the ease with which it is dissolved in the batch when in that form. That is, the alumina in the sand is no objection, because it is easily dissolved, and in the form of kaolin it is not. We know that kaolin is very difficult to assimulate. I think he is wrong when he speaks of the alumina in the sand being colloidal. It is more likely to be present as grains of feldspar, and I would like to ask in this connection whether any work has been done in the direction of introducing alumina into glass batch in the form of feldspar, and if so, what difference there may be in the behavior of a glass batch containing feldspar and one containing the same amount of alumina present in the form of clay?

Mr. Frink: I have tried those experiments in various ways. As I stated, when alumina was used in the form of clay, it was difficult to dissolve it, while in the form of feldspar we have already got a natural combination, and it goes into solution very easily and makes a very good glass. But the higher the feldspar within certain limits the more liable we are to have tough glass.

Mr. Binns: Difficulty of solution then is a function not necessarily of the alumina, but a function of the form in which the alumina is?

Mr. Frink: That is the idea, and that is the reason why I feel that when sand is used which carries alumina and is a little plastic, it will go into the glass very readily and melt much easier than any sand which contains the same amount of alumina by analysis but which exists grainy or in the form of kaolin.

THE BEHAVIOR OF FIRE BRICKS UNDER LOAD CONDITIONS AT A TEMPERATURE OF 1300°C.[1]

BY

A. V. Bleininger and G. H. Brown, Pittsburg, Pa.

PRELIMINARY STATEMENT.

In this paper the writers are dealing with the definite problem of the load-carrying ability of fire bricks, and they make no claim that the test described by them will discriminate as to the general usefulness or value of a refractory. A material which might make a poor showing in this test might be useful for many purposes, where the strength at the temperature employed is a minor consideration.

In the study of the effect of heat upon clays and clay mixtures, it is necessary to keep in mind the fact that the phenomena of fusion are by no means confined to temperatures close to the so-called melting or softening point, but manifest themselves already at heats hundreds of degrees below the stage of viscous fusion. In fact, we can say that clays and and clay mixtures do not possess a definite melting point. In testing a specimen of fire clay or of fire brick, fusion is said to have taken place when the test pyramid or specimen has softened sufficiently so that its edges are rounded, and it has bent over in the well known manner. As a matter of fact, for all practical purposes, a fire brick would have been completely distorted, and would have shown all signs of fusion at considerably lower temperatures owing to its inability to support its own weight. It is simply due to the viscosity of the mass and to the fact that no load is imposed upon it, that it does

[1] By permission of the Director, U. S. Geological Survey.

not show the distortion coincident with softening. It is evident, therefore, that the determination of the so-called melting point of a clay or fire brick, though useful in differentiating between low and high grade materials, does not offer a reliable means of expressing the entire refractory behavior.

Thus Purdy[1] found the fusion points of evidently inferior clays to be quite high. He reports, for instance, a clay of the formula $5.1\ SiO_2 \cdot Al_2O_3 \cdot 0.046\ Fe_2O_3 \cdot 0.09\ TiO_2$ to have a "fusion" point corresponding to cone 32. Similar results have been obtained in the Survey laboratory at Pittsburg.

The function of viscosity in extending the softening period is clearly recognized by all who have worked with silicates.

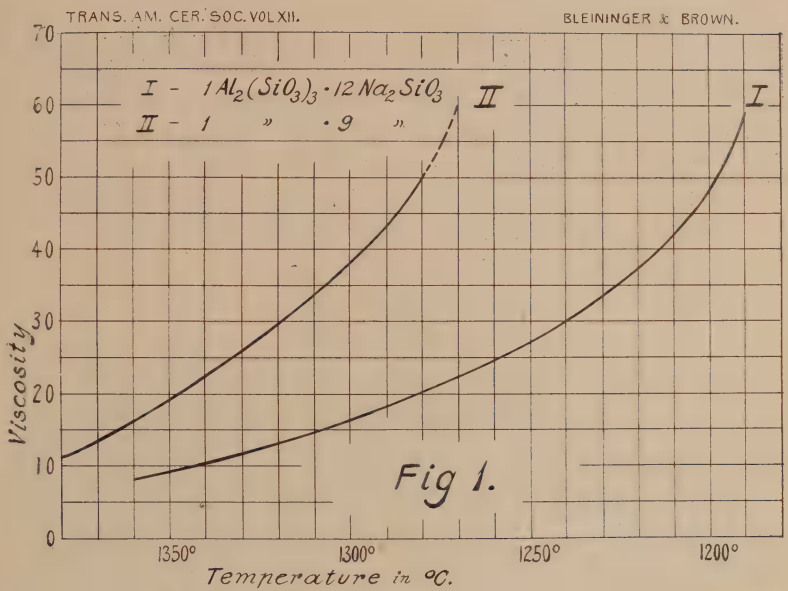
Thus Day and Allen,[2] in their investigations, bring out this point very clearly. Doelter, and his students in fact, have endeavored to determine the viscosity of different silicates at various temperatures. Vogt, likewise, has sought to correlate the viscosity of fused magma with the sequence and velocity of crystallization.

Greiner[3] determined, by means of a specially constructed apparatus, the viscosity of mixtures of Na_2SiO_3 with various other silicates at different temperatures. Thus, in a mixture of Na_2O, SiO_2 and Al_2O_3 he found that the viscosity was greatly increased by the addition of as small an amount as 2.5 per cent of Al_2O_3. This is shown graphically in Fig. 1, where the abscissæ represent the temperatures and the ordinates the relative viscosity. Curve I corresponds to the formula $Al_2O_3 \cdot 12\ Na_2O \cdot 15\ SiO_2$ and Curve II to $Al_2O_3 \cdot 9\ Na_2O \cdot 12\ SiO_2$. If alumina thus increases the viscosity of Na_2SiO_3, which is one of the most mobile silicates, it is evident that the internal

[1] Ill. State Geol. Survey, Bull. No. 4, p. 133.

[2] The Isomorphism and Thermal Properties of the Feldspar, Carnegie Inst., 1905.

[3] Inang. Dissertation, Jena, 1907, p. 17.



friction of highly aluminous combinations must be very high indeed.

On the other hand, the criticism raised as regards melting point determinations, does not apply to silicious mixtures containing a base-like lime. In testing silica brick it has been found that the melting point is well defined, as we should expect from our knowledge of the calcium silicates. Such a brick will stand up well in the fire, even under heavy loads, without deformation, at temperatures at a safe interval below its melting point. There is practically no flow until the melting point has been reached, when it will suddenly fuse to a liquid of low viscosity. This is probably the reason why silica brick are now being employed in many places where load conditions are an important factor, as in gas benches, etc.

In order to overcome the viscosity effect of the fused mass it evidently seems desirable to bring about conditions which will neutralize it. For this reason some investigators have found it advisable to apply a slight load to the

specimens to be examined. In some cases a platinum weight is used which is placed on top of the small cylinder or cone in the furnace. Howe[1] has suggested a furnace illustrated in Fig. 2, which arrangement makes it possible to measure the rate of settling or flow as well.

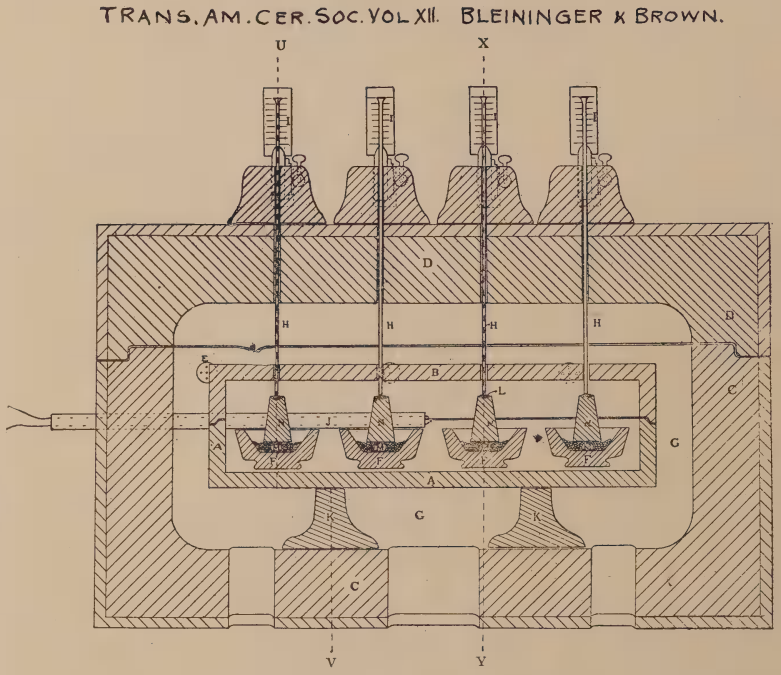


Fig 2.

For the solution of the problem at hand, viz., the resistance of fire bricks to load conditions, it was decided not to approach the softening temperature proper, at which the whole mass becomes a viscous liquid, but to restrict our work to average furnace temperatures at which only the more fusible silicates are softening. In the average fire brick, containing from 80 to 85% of flint clay and

[1] Metallurgical Laboratory Notes, p. 50.

20 to 15% plastic bond clay, it is obviously the character of the latter which would determine the behavior of the brick from this standpoint, since the flint clay within this region shows no fusing action whatever. In order to bring out the point sought, it was evidently necessary to apply loads somewhat greater than those used in practice, though it was realized that it must not be excessive.

DESCRIPTION OF TEST.

In preparing for this investigation the work of Lemon Parker[2] was consulted, whose interesting results were

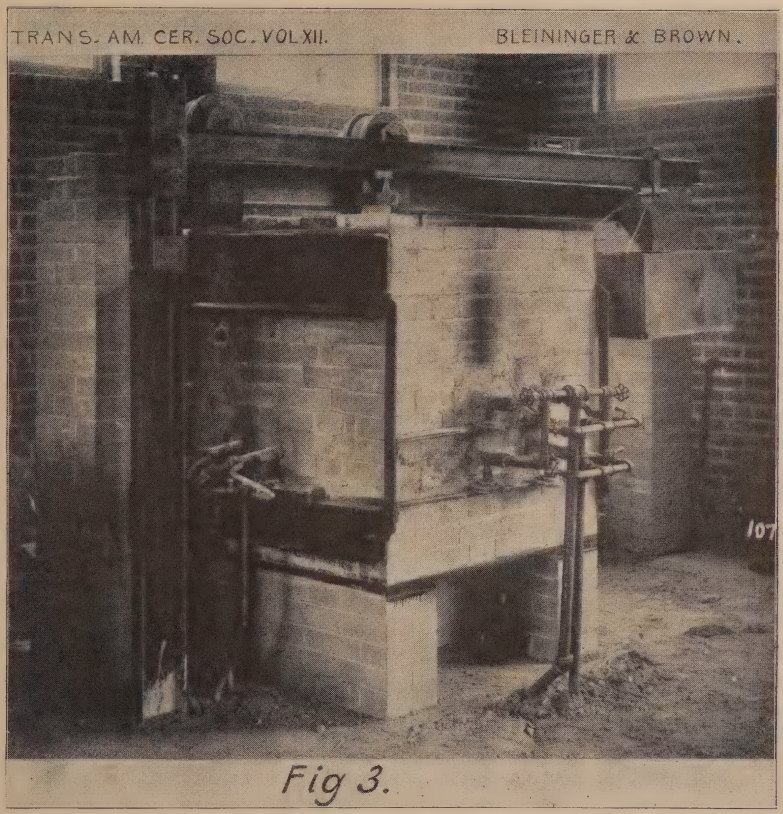


Fig 3.

[2] Transactions American Ceram. Soc., Vol. 7, Part II.

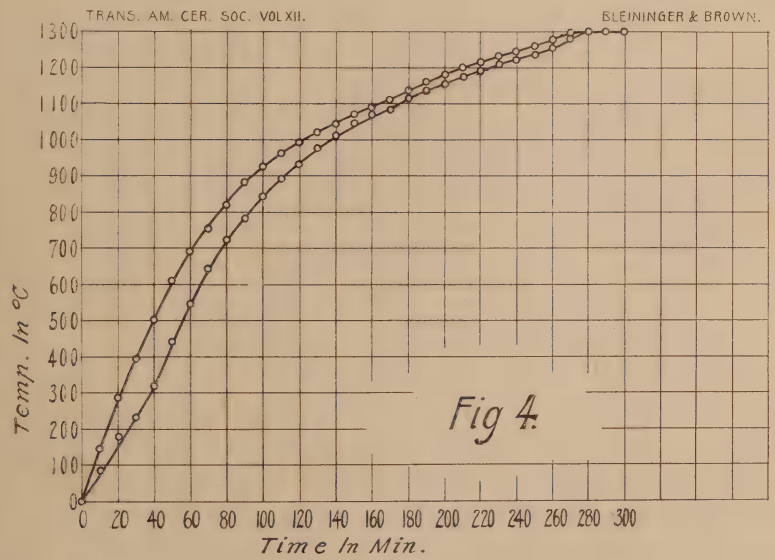
found very suggestive, though in his work only small specimens were used.

Since it was thought advisable to use full sized bricks, a furnace was constructed as illustrated in Fig. 3, with an interior space of 20″x 20″x 21″, heated by means of eight Fletcher burners, which were supplied with natural gas and compressed air. The combustion gases escape through holes along the back side of the furnace, which consists of a movable door made from a heavy wrought iron frame lined with fire bricks. This frame is hung from two rollers running on an overhead track, so that it can be easily moved. The brick to be tested is firmly placed on end upon a heavy fire clay block about 9 inches from the door, and made to set plumb by means of fire clay mortar. The half of a chrome brick is then placed upon the test specimen and on top of it a long cylinder, made from high grade fire clay which extends through a hole in the arch of the furnace. The load is then applied upon a cast iron knife-edge plate by means of a steel I-beam 9 ft. long, with a distance of three feet between the pin taking the up-thrust and the fulcrum, and six feet between the latter and the point of load application. The weight of the beam is 155 pounds. The weight applied consists of a wooden box containing the necessary amount of iron shot. The beam was first calibrated by means of a platform scale. The pin at the one end of the beam passes through a cast-iron block sliding in a channel iron provided with a slit and a heavy fastening bolt. On top of the block two bolts are arranged so that it can be lowered by loosening the fastening bolt and tightening up the top nuts. In this manner the I-beam may be kept level throughout the test, thus avoiding any side strains upon the brick.

Through an opening in the door a thermo couple is inserted, which is placed as close to the brick as possible. The junctions of the element are placed in test-tubes immersed in a beaker of water, the temperature of which is read regularly.

Before beginning the regular tests it was, of course, necessary to determine the best working temperatures and pressures for the purpose in view, and in this the experience of Mr. Parker, as given in the article cited above, was used as a guide.

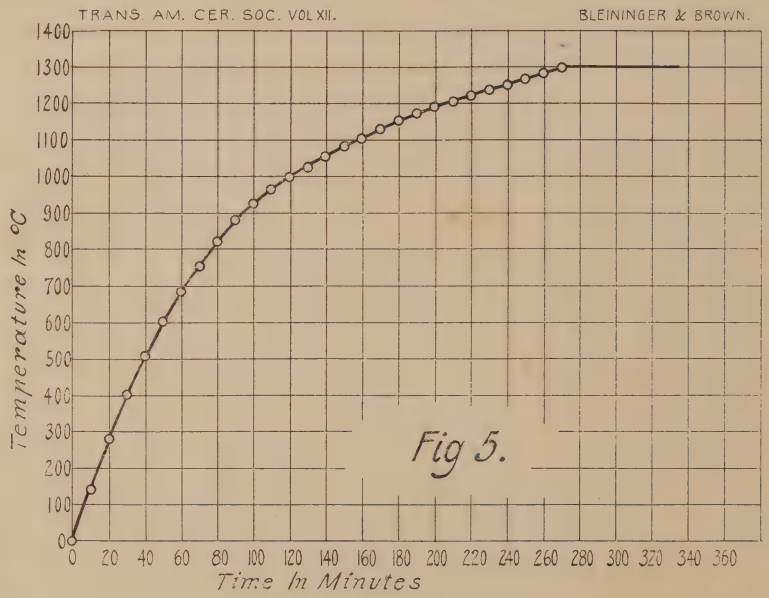
The first point it was necessary to determine was the rate at which a fire brick could be heated up, and the time required until the interior of the test specimen had assumed the temperature of the furnace. For this purpose a hole was drilled to the center of a brick. A thermocouple was then inserted and the hole well plugged up, leaving the couple well covered for some distance away from the brick. Another couple was placed close to the brick, but not touching it. Fig. 4 shows the time-temperature curves



resulting from this test, which illustrate that after 285 minutes, at the rate of heating followed, the inside temperature was the same as that on the outside. Since it was necessary to conduct the test with reasonable rapidity, owing to the limited hours during which power was available,

the time-temperature curve shown in Fig. 5 was finally adopted.

The temperature to which the brick was to be brought and held for one hour in one series of tests was taken to be 1300°C., based on the consideration that the more easily fusible combinations of silicate mixtures vitrify and soften within this heat region. In the second series the temperature was raised to 1350°C. The tests described in this



article refer to the former temperature. As regards the loads to be used, a considerable number of preliminary tests were made with pressures ranging from 125 pounds to 50 pounds per square inch, but in the first series a load of 75 pounds per square inch was employed, and in the second, 50 pounds. The present results refer to the 75 pound load condition maintained for one hour at 1300°C.

In addition to the load tests, the following determinations were made:

1. Crushing strength of the bricks on end in the cold condition.
2. Chemical analysis.
3. Softening temperature.
4. Porosity.
5. True specific gravity.
6. Decrease in water absorption on re-burning to cone 12.

1. The crushing strength of the bricks, placed in the machine endwise, was carried on in the usual way, pains having been taken to imbed the specimen in plaster.

2. For the purpose of the chemical analysis, a sample sufficiently large was obtained by breaking up two half bricks and crushing them to pass the 100 mesh sieve. The disintegrated sample was allowed to flow in a small stream over a powerful magnet until all of the particles of metallic iron were removed. The analysis was carried on under the supervision of Mr. P. H. Bates, chemist in charge of the structural materials chemical laboratory, assisted by Mr. A. J. Phillips. The methods advocated by Hillebrand were used throughout this work.

3. The softening temperature was obtained by chipping off specimens from the bricks and placing them in a Fletcher gas furnace, using preheated compressed air and natural gas. For the higher temperatures a small carbon resistance furnace was employed, in which the muffle consisted of a body containing 85% calcined alumina and 15% of kaolin, Fig. 6. This furnace was found very satisfactory for the purpose. Seger-Orton cones were used for the determination of the temperatures. The results were checked in each case.

4. The porosity was determined by obtaining the weight of a dry piece of the brick, the weight of the same specimen saturated with water by boiling in vacuo and the suspended weight. The results checked practically with the porosity, calculated from the true and apparent specific gravities.

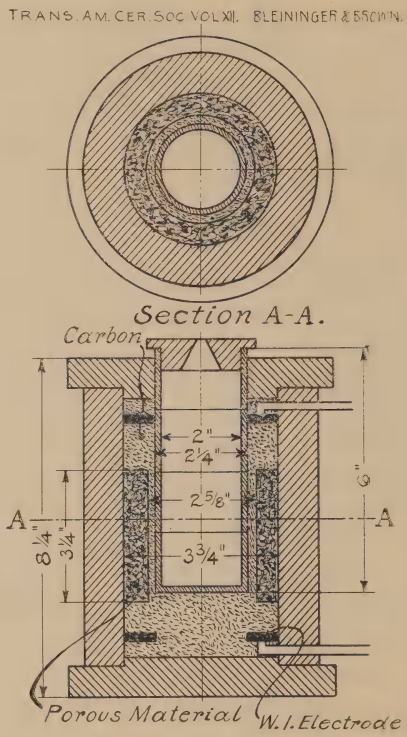


Fig 6.

5. The true specific gravity was obtained from 50 gram samples of the pulverized bricks, under the customary precautions as to the removal of air by boiling in vacuo and making corrections for the final temperature of the water.

6. The original weighed bricks in this case were tested for water absorption by placing them flatwise in a covered tank, containing 1½ inch of water, for 48 hours. After weighing they were dried and burnt in a down-draft test kiln to cone 12. They were then again immersed as before, and the water absorption determined.

In this work 26 brands of fire bricks were tested, and each manufacturer was requested to furnish 20 bricks.

The writers desire to take this opportunity for thanking the various companies for their co-operation, and the interest taken in this work.

RESULTS OF TESTS.

In Table I the chemical analyses, as well as the calculated empirical formula, are compiled.

The results of the physical tests are arranged in Table II, and the data referring to the load test, as has been said above, apply to the load of 75 pounds per square inch and the temperature of 1300°C.

TABLE I.

Chemical Analyses.

No	% Silica	Alumina	Titanium Oxide	Ferric Oxide	Lime	Magnesia	Potash	Soda	EQUIVALENTS								
									SiO_2	Al_2O_3	TiO_2	FeO	CaO	MgO	K_2O	Na_2O	RO^{*}_{3}
1.....	81.60	14.55	0.49	1.15	0.37	0.27	1.08	0.67	9.180	1.0	0.041	0.098	0.045	0.046	0.079	0.074	0.342
2.....	79.20	17.42	0.49	1.19	0.21	0.38	.91	0.37	7.732	1.0	0.036	0.087	0.022	0.056	0.057	0.035	0.257
3.....	77.02	18.35	0.52	1.32	0.48	0.28	1.49	0.67	7.140	1.0	0.036	0.092	0.037	0.038	0.088	0.060	0.315
4.....	54.58	37.35	1.57	4.10	0.54	0.53	1.02	0.42	2.485	1.0	0.054	0.140	0.026	0.036	0.030	0.019	0.251
5.....	54.70	39.72	1.86	1.32	0.29	0.52	1.07	0.64	2.343	1.0	0.057	0.042	0.013	0.033	0.043	0.038	0.169
6.....	54.69	38.86	1.92	1.41	0.35	0.52	1.57	0.91	2.386	1.0	0.064	0.046	0.016	0.034	0.044	0.038	0.178
7.....	54.25	38.90	1.92	1.83	0.41	0.78	1.26	0.78	2.365	1.0	0.064	0.060	0.019	0.051	0.035	0.033	0.198
8.....	52.30	41.52	2.46	1.28	1.02	0.45	0.94	0.28	2.142	1.0	0.075	0.039	0.045	0.028	0.025	0.011	0.148
9.....	63.89	29.28	2.40	2.05	0.27	0.29	1.71	0.40	3.710	1.0	0.105	0.089	0.017	0.025	0.063	0.022	0.216
10.....	60.37	34.83	2.05	1.37	0.39	0.31	0.67	0.20	2.947	1.0	0.075	0.050	0.020	0.023	0.021	0.009	0.123
11.....	61.35	32.65	1.98	2.15	0.46	0.50	0.86	0.17	3.196	1.0	0.077	0.064	0.026	0.039	0.029	0.009	0.167
12.....	55.66	36.52	2.40	2.59	0.49	0.61	1.73	0.18	2.591	1.0	0.085	0.090	0.024	0.043	0.051	0.008	0.216
13.....	68.73	25.12	1.32	2.26	0.36	0.49	1.62	0.25	4.651	1.0	0.067	0.115	0.026	0.050	0.070	0.002	0.263
14.....	60.77	32.63	1.94	2.89	1.12	0.26	0.46	0.26	3.168	1.0	0.076	0.113	0.063	0.020	0.015	0.013	0.224
15.....	56.55	36.64	1.90	2.84	1.34	0.22	0.43	0.32	2.634	1.0	0.066	0.099	0.067	0.015	0.013	0.014	0.208
16.....	50.76	44.24	2.03	1.45	0.33	0.29	0.60	0.34	1.952	1.0	0.059	0.042	0.014	0.017	0.015	0.013	0.101
17.....	62.14	32.29	1.42	2.65	0.71	0.50	0.38	0.13	3.294	1.0	0.051	0.104	0.040	0.039	0.013	0.007	0.203
18.....	62.74	31.80	1.53	2.45	0.75	0.56	0.18	0.18	3.354	1.0	0.061	0.100	0.043	0.037	0.006	0.009	0.195
19.....	35.46	57.98	2.70	1.40	0.29	0.29	1.30	0.75	1.040	1.0	0.059	0.031	0.009	0.013	0.014	0.021	0.088
20.....	52.89	43.41	2.12	0.90	0.16	0.13	0.27	0.36	2.072	1.0	0.062	0.003	0.004	0.076	0.007	0.016	0.106
21.....	65.41	29.50	1.38	2.75	0.45	0.25	0.34	0.10	3.770	1.0	0.060	0.119	0.003	0.022	0.013	0.006	0.163
22.....	66.53	28.66	1.36	2.35	0.58	0.42	0.19	0.28	3.930	1.0	0.060	0.104	0.037	0.037	0.007	0.016	0.201
23.....	66.28	29.12	1.79	1.55	0.59	0.23	0.30	0.27	3.871	1.0	0.078	0.069	0.037	0.020	0.011	0.015	0.152
24.....	77.82	19.00	1.65	1.01	0.22	0.06	0.28	0.10	6.953	1.0	0.111	0.068	0.021	0.008	0.016	0.009	0.122
25.....	56.62	39.19	1.69	1.95	0.36	0.08	0.19	0.18	2.458	1.0	0.055	0.063	0.019	0.005	0.005	0.008	0.100
26.....	54.51	40.42	2.46	1.90	0.35	0.17	0.20	0.16	2.293	1.0	0.028	0.060	0.016	0.011	0.005	0.007	0.099

*$RO = K_2O + Na_2O + CaO \times MgO + FeO$

TABLE II.

Physical Tests.

No	Crushing strength, cold lbs per sq. in. Brick on end.	% Porosity	True Specific Gravity	Softening Temp. in Cones	Height of brick before load test. Inches	Height of brick in inches after load test	Temp. at which deflection started. °C	Compression of brick in inches	% Water absorption of brick in terms of dry wt.	% Water absorption of brick in terms of dry wt. after reburning to cone 12	Decrease in water absorption on reburning
1	1464	30.2	2.591	28	9	Crushed	1213	Crushed	12.89	12.00	0.89
2	1289	30.1	2.592	28	9	Crushed	1247	Crushed	12.90	10.12	2.78
3	989	32.4	2.656	28	8 7/8	Distorted	1210	Badly Distorted	11.47	5.53	5.94
4	495	25.8	2.737	29	9	Crushed	1180	Crushed	9.97	7.55	2.42
5	1160	23.0	2.670	31 1/2	8 7/8	8 1/8	1191	3/4	10.31	7.53	2.78
6	931	22.9	2.632	31	9	8 1/4	1213	3/4	8.75	7.22	1.53
7	674	20.7	2.671	31	9	7 3/4	1215	1 1/4	7.35	4.46	2.89
8	1082	17.1	2.640	34	8 3/4	8 3/8	1082	5/8	13.18	8.57	4.61
9	612	29.4	2.651	29 1/2	8 7/8	Crushed	1191	Crushed	13.08	9.60	3.48
10	946	27.5	2.662	33—	8 7/8	8 1/2	1179	5/8	11.17	8.36	2.81
11	480	25.1	2.669	28	9	7 1/2	1133	1 1/2	9.13	4.13	5.00
12	2614	24.5	2.640	26	9	Crushed	1142	Crushed	10.49	5.00	5.49
13	843	22.5	2.658	28 1/2	8 3/4	Crushed	1130	Crushed	8.55	6.55	2.00
14	2226	25.5	2.707	31 1/2	8 7/8	8 5-16	1211	9-16	8.88	7.39	1.49
15	1638	23.1	2.672	32	8 7/8	7 7/8	1234	1	10.72	8.34	2.38
16	971	24.3	2.678	34	9	8	1205	1	8.82	7.23	1.59
17	2578	23.9	2.629	31	8 3/4	8 1-16	1233	13-16	.....	.....	....
18	955	21.0	2.638	33—	8 7/8	8 3-16	1274	13-16	15.56	12.51	3.05
19	2071	33.3	2.991	33—	9 1/8	8 1/2	1235	5/8	13.98	10.84	3.14
20	1005	26.8	2.694	31	8 3/4	8 1/2	1213	1/4	8.59	7.68	0.91
21	3174	22.2	2.642	32	8 7/8	8 9-16	1231	5-16	11.15	10.22	0.93
22	2191	26.8	2.662	31	8 7/8	8 1/4	1234	5/8	9.53	8.20	1.33
23	4234	23.9	2.649	30	8 7/8	8 5-16	1264	9-16	12.39	10.42	1.97
24	2551	27.5	2.600	29	9	8 7/8	0	1/8	12.62	8.76	3.86
25	1241	26.3	2.695	31 1/2	9	8 3/4	1291	1/4	11.90	6.42	5.48
26	1138	22.3	2.685	31	8 7/8	7 5/8	1207	1 1/4	.....	.....	....

Fig 7.

Fig. 7 represents the fracture resulting from the crushing test in the cold. The break is normal, and agrees with the theoretical considerations. In the following plates the photographs of the fire bricks, after having been subjected to the load test, are reproduced.

TRANS. AM. CER. SOC. VOL XII.
BLEININGER & BROWN
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5
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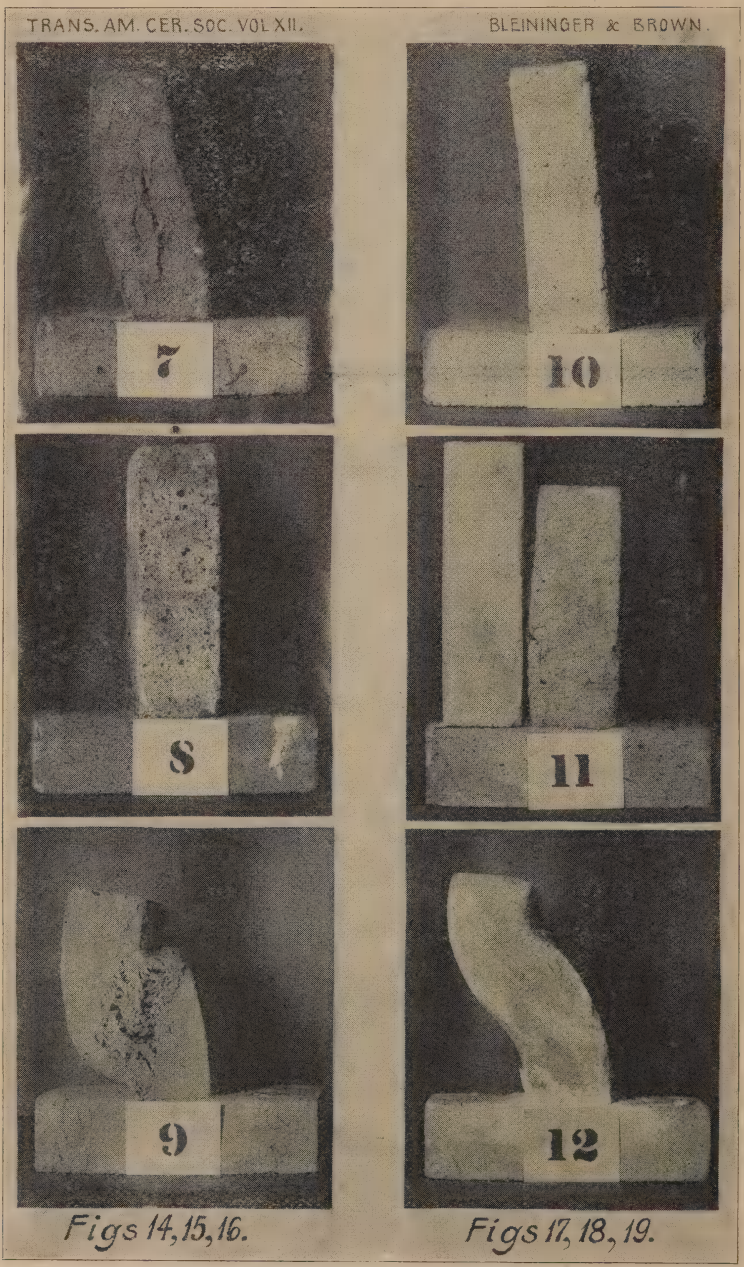
Figs 8,9,10.
Figs 11,12,13.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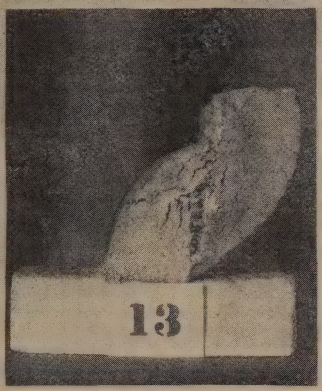
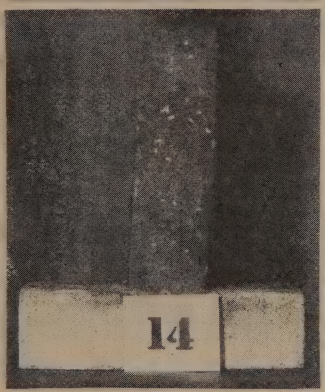
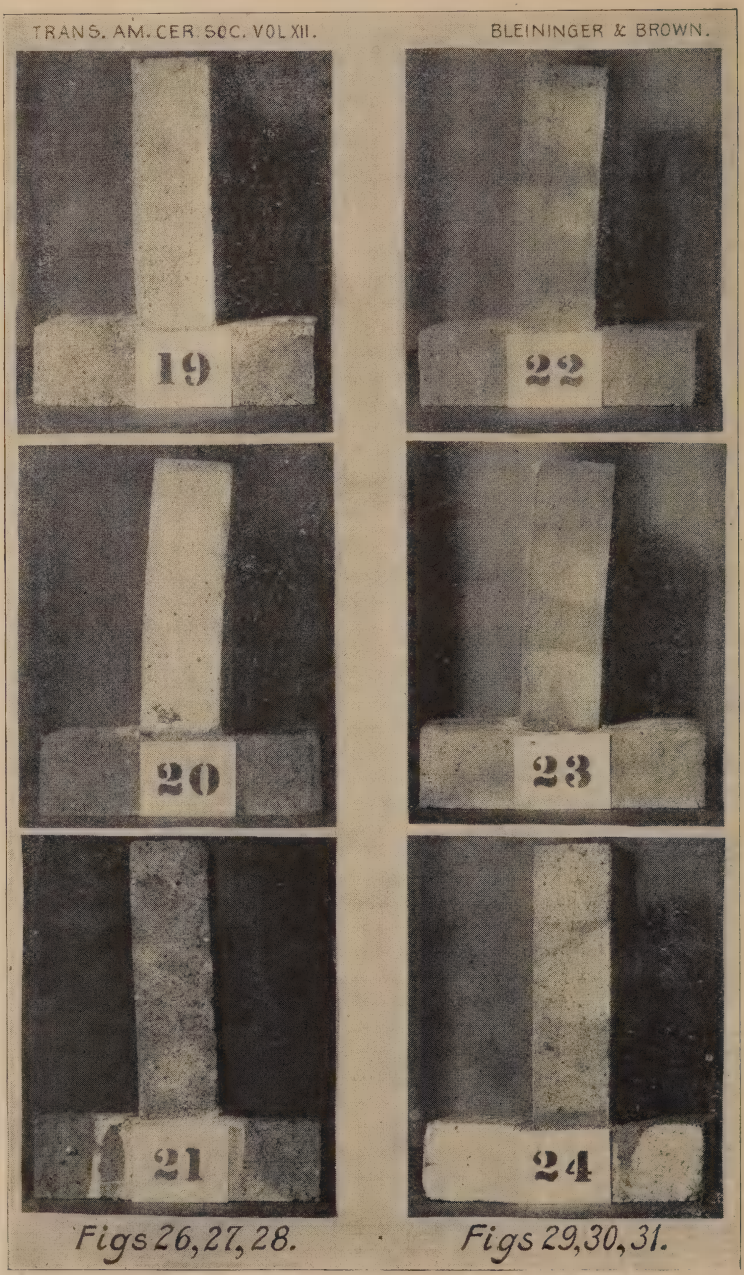
Figs 17, 18, 19.





Figs 20, 21, 22. Figs 23, 24, 25.



Figs 26, 27, 28. Figs 29, 30, 31.

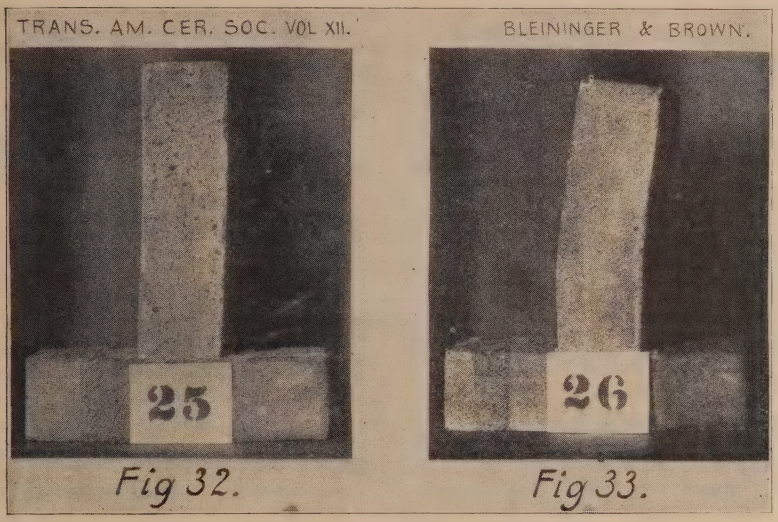


Fig 32. Fig 33.

From these it appears that in the cases where the bricks were badly distorted and crushed, in each case a certain degree of softening took place, as is clearly indicated by the curved surfaces. It is evident that these bricks attained a viscous condition in which they were not able to carry the load imposed upon them, though the latter is small compared with the crushing strength at the atmospheric temperature. In no case is the fracture as sharp as is shown in Fig. 7, but invariably clear evidence of flow is produced.

In carrying on the load test as the temperature rises, the beam is first raised, due to the expansion of the furnace bottom and the brick, a quiescent stage is then reached after which, from 1130 to 1290°, a well defined deflection begins, caused by the contraction of the brick. In some bricks this deflection continues at a very slow rate, or reaches a condition of equilibrium some time after the temperature has been raised to 1300°. This kind does not fail under the conditions of the test, and the later deflection starts the more apt is the brick to stand up. The materials failing under this test show a more or less early

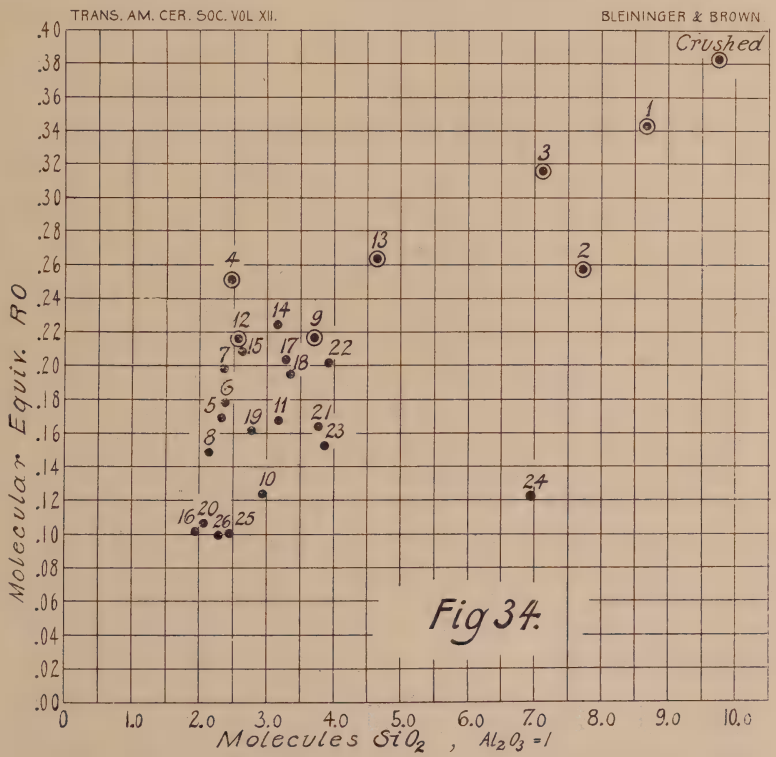
start in settling, and the rate at which this takes place increases with the temperature, till finally it becomes so rapid that it is impossible to keep the beam level. Failure then is merely a matter of minutes, and takes place very suddenly. In every case, therefore, softening precedes failure. With a third kind of material (of silicious composition, low in fluxes) the rise in height remains stationary for quite a while, followed by a long quiescent period. After the maximum temperature is reached a very slow and gradual settle takes place, which is quite small and decreases in rate as the temperature is kept constant. Such materials remain perfectly straight, and shrink but a small amount.

Undoubtedly some of the bricks tested would have been deformed badly on long time tests, which it was impossible to carry out under the conditions of the plant, but in several cases where the time of testing was extended considerably a kind of equilibrium seemed to be reached, after which no observable changes took place. It is very likely that in these cases solution of the more refractory portion of the brick took place, which stiffened up the bonding material.

Inspection of the failures shows plainly that the more refractory flint clay has not softened to the slightest extent. The grains have lost none of their original identity. They seemed to have slid upon each other, the bond clay acting analogously to a lubricant. From this it follows that, no matter how excellent the major constituent of the brick may be as to refractoriness, if the bond clay is deficient the load carrying power of the product is impaired. In other words, as far as this property is concerned, a fire brick is not any better than its weakest constituent.

It is observed that there is some rough relation between the softening temperature and the ability of the bricks to stand up under this test, but it is also seen that this is not true unqualifiedly. Test No. 16 is one of the decided exceptions. The failures not only show a softening

point below cone 30 but also a certain high content of fluxes, i. e., K_2O, Na_2O, MgO, CaO and FeO. On the other hand, while a brick may soften below cone 30, if its content of RO constituents is low it will resist the conditions of the load test without difficulty. In No. 24. we have an illustration of this kind, and many silica brick show similar results. Nevertheless, it seems quite clear that the load test is in a measure a determination of the refractoriness, in spite of the low temperature at which it is conducted.



No. 19 is not properly placed in this chart, as will be seen by reference to Table I.—Editor.

In Fig. 34 the failures due to the crushing of the bricks are plotted, and it is observed at once that the most

significant factor seems to be the RO content. It is not to be expected that a sharp division line exists between the area of failure and that of satisfactory load carrying ability, since in some cases the FeO, which constitutes part of the RO, may be present in the form of larger grains, in which condition it is not detrimental. The fact is again shown that neither the softening temperature nor the chemical analysis alone produces the information brought out by the load test. Given all three of these data, however, a very good presentation of the refractory resistance of a fire brick is obtained.

Examining the question from the chemical standpoint, and assuming that the fire brick body consists of a refractory constituent corresponding in composition to the kaolin formula, and of a more fusible cementing component, the following method might be pursued, taking for example one of the failures, say sample No. 4. The entire brick, on calculation from the average analysis, possesses the empirical formula: 0.019 Na_2O, 0.030 K_2O, 0.036 MgO, 0.026 CaO, 0.14 FeO, 0.054 TiO_2, 1.00 Al_2O_3, 2.485 SiO_2. Assuming that the alkalies are derived from feldspar, the alumina corresponding to 0.019 + 0.030 alkali is 0.049 equivalent. Deducting this from 1 we obtain 0.951 equivalent of clay substance, which contains 1.902 equivalent of silica. Subtracting this from 2.485 leaves 0.583 silica. Beside 0.951 equivalent of pure clay base, this would leave the rest of the constituents to form the more fusible mixture: 0.019 Na_2O, 0.030 K_2O, 0.036 MgO, 0.026 CaO, 0.14 FeO, 0.049 Al_2O_3, 0.583 SiO_2. Throwing this into another formula with RO equal to unity, we obtain: $RO \cdot 0.195\ Al_2O_3 \cdot 2.322\ SiO_2$. It is the amount and character (fusibility and viscosity) of this mixture which should govern the refractory behavior of the product under load conditions. From a rough estimate, it would seem that this composition is analogous to a quite fusible clay or acid slag, with comparatively low viscosity. The amount of this mixture might be calculated as follows:

$0.049 \cdot 37.35 =$	1.83%	Al_2O_3
$0.583 \cdot 54.58 =$	12.83%	SiO_2
	3.69%	FeO
2.485	0.54%	CaO
	0.53%	MgO
	1.02%	K_2O
	0.42%	Na_2O
	20.86%	

In this case, then, the fusible silicate mixture of the formulua $RO \cdot 0.195\,Al_2O_3 \cdot 2.322\,SiO_2$ would constitute 20.86% of the total weight of the brick body, sufficient to cause it to behave as it did in the load test. In this theoretical speculation we must keep in mind that the effect is more marked, owing to the heterogeneous mixture of the assumed pure flint and impure bond clay. The more thoroughly the two materials are ground and blended together the better would the body behave in the load test, until finally the effect would be that corresponding to a single clay of the average composition, though even in this case it would remain a somewhat inferior material, owing to the high content of fluxes. The more impure the bond clay, therefore, the more complete and intimate should the mixture be.

An analysis of the relation between the initial, cold-crushing strength and the load behavior, shows no apparent connection, but the fact is brought out that low inital strength is a handicap. Bricks Nos. 4 and 11 are examples of this observation. While No. 4 would have failed irrespective of its cold-crushing strength, the failure was more complete on account of its weakness, and No. 11 in all probability would have shown a very much smaller condensation, in fact, would have stood the test.

The hardness of burning in a general way is a factor worthy of consideration. Although burning to a high temperature cannot, in the nature of the case, effect any fundamental change, and cannot convert a low grade material into a good one, our work has shown that well burnt bricks stand up better than soft burnt products. This is due, not only to the greater compactness of the body, but also to

the change in the composition of the bonding material where such is used. In other words, hard burning will cause the plastic clay, usually decidedly less refractory than the flint, to dissolve some of the fine part of the better material, thus increasing its own refractoriness and hence its resistance to load conditions. For instance, No. 26 would have shown up better if it had been burnt harder.

To what extent other changes, such as the formation of sillimanite at higher temperatures, would have a beneficial effect, it was not attempted to determine.

For the purpose of selecting materials for Government use, the tentative requirement was made that under the conditions of this test a 9″ brick should not shorten more than one inch.

The results of the second series of tests in which the load is 50 pounds per square inch and the temperature 1350°C., are very much like those obtained in the first series, but appear to bring out more the question of flow due to softening being somewhat less dependent upon the initial strength of the brick. It is intended to use the latter conditions in all further work.

REFRACTORIES MADE FROM ONE CLAY.

As to fire bricks made from a clay material which is sufficiently plastic so as to be used alone, it is clear that its ability to carry loads depends simply upon its composition. Some of the very best tests have been obtained from materials of this kind. This case is the simplest and needs no particular attention, since a clay will stand up or fail by virtue of its own quality. A pure clay of moderate plasticity would be the ideal material for the manufacture of fire brick. Since, however, such clays are usually not available, the question of judging them as to their composition deserves some attention from the standpoint of their load carrying capacity. From this point of view the most important consideration is that of the amount of fluxes.

At the high temperatures involved, the presence of

even a small amount of fluxes becomes a potent factor, and hence it is far better to select a clay higher in silica and low in fluxes than a clay possessing the silica-alumina ratio of koalin but higher in fluxes. The effect of silica in lowering the refractoriness of clays is commonly exaggerated as far as practical results are concerned, and it is usually not necessary to reject a clay on this account. However, high silica and high fluxes make a dangerous combination. From this it follows that a clay fairly high in fluxes, corresponding for instance to $0.22\,RO \cdot Al_2O_3\ 2\,SiO_2$, would be improved by the dilution with a silicious material low in fluxes, or even by the addition of a clean sandstone, the principal requirement being intimate blending and grinding.

In regard to the fluxes present in a clay, the state and size of grain of the iron is of importance, for it is evident that coarser grains of iron minerals will do no harm, though in the analysis they contribute their share towards raising the amount of fluxes. An effort should be made to determine the amount of such grains and to make the proper correction in the analysis.

The fluxes are an important factor in the ability of refractories to carry loads, inasmuch as they become active at low temperatures, as has been shown in the table of results, by forming easily fusible silicates. As the temperature rises increasing amounts of silica and alumina are dissolved, and it becomes, therefore, simply a matter of the amount of this fused matter and its viscosity, whether or not a given refractory will stand up at the temperature in question. As the temperature rises or the load is increased, a point is reached where the entire body becomes too viscous to retain its shape.

By grinding the clay as coarse as possible, conditions are improved, as in doing this the formation temperature of the fusible silicates is raised, since the process of solution is hindered, and by these means it may be possible to bring the product out of the danger zone. In time, however,

equilibrium conditions are approached closer and closer, so that finally the brick may fail under the same conditions under which they stood up at first.

BRICKS MADE FROM FLINT AND BOND CLAY.

In this case we are dealing with comparatively coarse grains of flint and fine grains of bond clay. These two materials are mixed and blended as far as the processes customary at the present time permit it. The bond clay breaks up more readily, and the plastic mass produced by it cements together the grains of flint clay and calcine. Assuming that the flint clay is of good quality, the load carrying capacity of the product depends upon the bond, as has been shown above. It is evident that if the flint is inferior the product suffers accordingly. These two materials may be considered from the standpoints of chemical composition, vitrification range and fineness of grain.

Flint Clay.

This material, the geological origin of which is still in dispute, is deficient in plasticity, although by very fine grinding it may become sufficiently plastic to be molded. It is of conchoidal fracture, often quite hard, and at its best approaches pure kaolin in composition, being often surprisingly low in fluxes. Its drying shrinkage is practically nil, but in burning it suffers as a rule a decided contraction in exterior volume. Its refractoriness, when pure, is very high. A brick made from flint clay (by fine and long continued grinding) is able to carry high loads. The vitrification range of flint clay has been well shown in the paper by Knote, in this volume. As far as refractoriness is concerned, it is good practice to grind it quite coarsely for reasons already indicated. The fact that occasionally it is in part calcined does not affect its refractory behavior, but simply corrects the shrinkage suffered in burning.

The physical characteristics of flint clay are not al-

ways a synonym for high refractory quality, as the writers have seen clays of this type which are decidedly inferior.

Plastic Bond Clays.

In these materials a good grade of plasticity is desirable, though this is less important where their refractoriness is high. In clays of greater fusibility high plasticity enables the manufacturer to cut down its amount to a minimum. In the selection of a bond clay it is evident that its vitrification range should be as long as possible, i. e., the temperature at which it becomes dense and non-absorbent should be as high as possible. The chemical composition and inherent mineral structure are thus most readily expressed by means of porosity-temperature curves, such as have been frequently described in these transactions, and which have been employed by Purdy in the study of Illinois fire clays. In making such tests, the time of burning should approach as much as possible the duration of the burns in actual practice. What has been said of the chemical composition of clays under the head of bricks made from one clay applies also here. The main consideration is that the amount of fluxes be as low as possible, irrespective of the silica or alumina content.

As to fineness of grain, it might be said that the grinding should not be carried any farther than is necessary to develop good plasticity.

Improvement of Bond Clay.

If a flint-bond-clay mixture should prove unsatisfactory as regards its ability to carry loads, the first step would be to cut down the amount of plastic clay if possible. If this should not be possible or beneficial, the plastic material could be improved by grinding it intimately with a portion of the flint clay to such a degree of fineness as would insure thorough incorporation. This could be done by dry or, preferably, wet grinding. In the latter case it might be possible to pug the additional, coarser flint clay into the slip, which naturally would be maintained as thick

as possible. The finely ground flint would not remain inert but would be sure to possess some plasticity.

Another alternative would, of course, be the substitution of another clay for the unsatisfactory plastic bond. Since not infrequently silicious clays are at hand, this might prove feasible, even though the amount of bonding material would have to be increased. Where the flint clay is becoming scarce, it might be possible to find some soft sand rock which could be ground into the plastic bond clay, and which would thus improve its behavior under load conditions.

By some such means as have been indicated here, it would not seem a difficult matter in most cases to manufacture products fulfilling all reasonable conditions as to crushing strength at the usual furnace temperatures. In addition, by paying attention to the sizing of the ground clays, so as to produce as dense a structure as possible, by the use of less water or by adopting dry pressing, the load carrying ability of the brick is increased. Likewise, burning at a higher temperature assists in bringing about the same result. Experiments carried on by the writers have shown that harder burning has increased the strength of fire bricks appreciably.

CONCLUSIONS.

1. The softening temperature of fire brick specimens is not a safe criterion of the resistance to load conditions at the average furnace temperatures. The same is true of the chemical analysis. By means of both the so-called melting point and the chemical analysis, the load behavior may be approximated. This cannot take the place, however, of a direct test. The RO constituents (including the iron as FeO) should be as low as possible, and for best results should not exceed 0.22 equivalent. The content of fluxes is more important than the silica content.

2. The test described appears to fulfill the requirements of a load test for fire brick, since the results are

consistent and admit of close checking. It is recommended that the load be fifty pounds per square inch and the temperature 1350°C. A No. 1 brick should show no marked deformation and should not be shortened more than one inch, for the standard nine inch length. The test estimates in a measure the refractoriness.

3. From the results of this test it appears that the amount and fusibility of the least refractory clay constituent govern the behavior of the brick under load. Improvement will result by grinding the less refractory clay intimately with flint clay or even silicious materials, low in flux, improving the density, and by harder burning.

DISCUSSION.

Mr. Parker: I certainly take a great interest in the paper of Professor Bleininger, as I at one time undertook to make investigations of this very kind, but all were at higher temperatures and with smaller loads. We were having trouble which was attributed to shrinkage, and I was soon satisfied that it was from some other cause. I would like to see these experiments carried a little further and at higher temperatures, which would result in data of very great value.

Mr. Hipp: I would like to mention that recently we have done some work along this line, although our appliances were nothing like Professor Bleininger's. I would like to ask whether Professor Bleininger thinks that the viscosity temperature, the temperature at which the bricks become viscous, has any direct bearing on the strength that the bricks might withstand?

Mr. Bleininger: It appears that the viscosity of the brick at lower temperatures is the principal cause of failure.

Mr. Hipp: Do you think burning the brick harder in manufacture would increase the strength?

Mr. Bleininger: I think so. It would tend to hold it up at higher temperatures.

Mr. Ramsay: As I understand Mr. Bleininger's remarks, the higher the crushing strength the better it will stand the heat. Take for illustration a fire clay, grind it very fine, and burn it in a kiln at a very high temperature. Will that brick stand more hot crushing strain than the brick that is not ground fine?

Mr. Bleininger: Given two bricks of equal refractoriness, the one with the greater initial compressive strength will have somewhat of an advantage. Fine grinding does not necessarily mean a decrease in porosity, but rather the reverse. The pores are smaller but the porosity is greater.

Mr. Ramsay: With coarse ground material the distance between the particles is greater than with fine ground. Under the heat conditions it takes longer to come in contact as they are further apart.

Mr. Bleininger: We must remember that where flint clay is used in making fire bricks we are dealing with two materials, the flint clay and the bond clay. The latter is, as a rule, very much finer than the former. By a suitable combination of coarse and medium fine flint and fine bond clay, the greatest initial strength is produced. It is evident that the more porous a brick is the less solid material it has to sustain the load. The coarser the clay is the longer it will resist the heat effect, but we must remember that in furnaces operated continuously we have a long time effect. It is obvious, however, that the bond clay cannot be coarse since this would defeat the purpose for which it is used. The weak point, therefore, is with the bond. If the latter is of high grade the brick will stand under the load, if not it will fail. But I have shown clearly how the product may be improved if the bond should not be of first quality.

Mr. Ramsay: I wish to bring out, if possible, what relation the cold crushing strain will have to the hot crushing strain?

Mr. Bleininger: There is very little relation. If a brick is physically weak under ordinary burning condi-

tions and is defective in composition, you can improve that material somewhat by making it stronger, but it will not be a fundamental remedy.

Mr. Ramsay: In other words, if one brick is soft burned and one is hard burned, the hard brick will stand the greater heat?

Mr. Bleininger: Hard burnt fire bricks seem to stand up better than soft burnt.

Mr. Hamilton: In Professor Bleininger's investigation he has found that the less refractory brick stood the greater test when cold?

Mr. Bleininger: The cold strength, as I have said before, has direct relation to the strength in the furnace. We have tested highly refractory materials that showed a good strength when cold.

Mr. Hamilton: And while the photographs do not show up as badly in the hot tests, that is the less refractory brick. Now, we make a brick that we think is very highly refractory. That would be a rough grained brick containing a binder of 20% of plastic clay. That brick would be very porous and I take it that the hot strain would be very low, but at the same time that brick would stand a greater heat than 1300 degrees where it did not come in contact with a load. A brick containing flint and bonded with 30% plastic clay would not show up as well, but would be a satisfactory brick for the roof of a furnace. The thing that I would like to find out is, would it be better to make a fine ground brick than one coarse ground? Your experiment has not shown that.

Mr. Bleininger: I want to say that I think I have been misunderstood. By grinding the whole brick mixture finer you of course improve the standing up quality of an inferior bond clay. But it is not necessary to do this. If for instance you were to grind the bond clay with some of the flint very fine, and then mixed this combination with your coarser ground flint, as usual, you would obtain the best result. I say distinctly that I am speaking of brick,

suitable for carrying loads at furnace temperatures, and realize fully that a brick may stand up at a high temperature if no load is imposed, while it would fail in this test. There is a very rough connection between the ability of a brick to stand up under this test and its so-called refractoriness. A brick softening below cone 30 would not stand much of a chance in the load test.

Mr. Parker: I think if Professor Bleininger goes a little farther in his experiments he will find that the results do not agree at higher temperatures. Beyond 1300 degrees C. they would not agree at all. At least that is my experience.

Mr. Bleininger: We selected the temperature because it is a very common furnace temperature.

Mr. Parker: I was compelled to go higher, and I found that one kind of clay standing unusually high temperatures was not as good a load carrier at a minimum temperature of 2400° to 2500° F. as a less refractory clay.

Mr. Hamilton: The point is, I do not think we can get a highly refractory brick sample and at the same time a brick that will stand up well under load conditions, because you cannot introduce the bond and hold up with the temperature.

Mr. Yates: At higher temperatures in the making of fire brick you take all the shrinkage out of your clay.

Mr. Hipp: I would like to say concerning the percentage of plastic clay used, that we made some tests recently, trying different amounts, and found that two bricks of practically the same refractoriness, one containing 30% of bonding clay and the other 50%, showed considerable difference as to their ability for withstanding the strain imposed. I would like to ask Professor Bleininger whether in testing two fire bricks, each containing a different amount of plastic clay but the porosity about the same in each brick, the crushing strength would vary to any great degree?

Mr. Bleininger: I cannot answer this question satisfactorily.

Mr. Ramsay: I think you have stopped too soon. We know your position in this line of work, and our customers would be apt to take your opinion rather than ours, and I think sometimes your conclusions are erroneous. I think that sometimes the clay used in bond has some effect upon the brick.

Mr. Bleininger: Of course, we stand back of our results, as they have been made with care, and I cannot retract one word of what I have said. When Mr. Ramsay speaks of the effect of the bond clay, I wish to call attention to the fact that this is the very thing which we have emphasized.

Mr. Parker: I would like to say that at higher temperatures Mr. Bleininger will find different results. At his temperature they agree with my experiments. You will find at higher tempertures that an ordinary fire clay promising good results as a load carrier, though still far from its fluxing point, may lose its efficiency in this respect, while the more refractory clay will prove more efficient with a moderate load to a temperature much nearer its fusion point.

BARIUM IN GLASS.

BY

R. L. FRINK, Lancaster, Ohio.

Does barium oxide add to or detract from the desirable properties essential to the satisfactory manipulation of glass, either by molds, free-hand blowing, or the mechanical process?

This is a question which I have endeavored to solve, both in an experimental and practical way, and while in some instances I have succeeded in demonstrating that certain properties are enhanced by the use of barium, in others I have met with a series of results which were so confusing and contrary, as to lead me to believe in the majority of instances this content is not as desirable as might be expected.

While it is true that barium gives to glass many desirable qualities, the principal of which are increased density and refractive index, considerable increase in the elasticity, tenacity and modulus of rupture, the lowering of the specific heat—which makes it very desirable for many uses, such as table ware, chimneys, globes, etc.—yet when melted in pots, or in the tank, it has a disagreeable and unsatisfactory way of separating, stratifying and laminating, so that when a lump is gathered and this is worked in any manner, it is quite liable to show a cordy condition. Further, if the barium exists in about the right percentage it devitrifies very easily and rapidly.

Some of the salesmen handling raw materials such as barium carbonate, make the claim that 100 pounds of barium will replace 150 pounds of lead, 200 pounds of lime, and 150 pounds of soda, and some of them even go so far

as to say that by the use of barium the soda can be reduced 25 per cent from the normal.

I will be pleased to hear the experience of any one who has had an opportunity to investigate this material in combination with silicates of lime and soda.

DISCUSSION.

Mr. Silverman: I would like to ask whether Mr. Frink found it possible to entirely replace lead by barium carbonate or barium oxide?

Mr. Frink: That question is a little bit ambiguous. In the replacing of lead by the use of barium you have got to know first what the ware is to be used for.

Mr. Silverman: For chimney purposes.

Mr. Frink: Yes sir, it can, in my estimation.

Mr. Silverman: If that is the case a big problem has been solved. In the manufacture of flint glass one of the greatest items of expense is the loss of pots through the reduction of the lead. The lead seems to seek weak spots in the clay, and work its way through; with barium carbonate reduction is rather difficult, so that if it can be employed for flint glass manufacture in the place of lead the manufacturer would greatly profit by the change.

Mr. Frink: Professor Silverman touched on exactly what I wanted to bring out in that paper. In the use of lead glass for most all purposes, we have got a condition which is analogous to barium, that is a non-homogeneity of the metal by the use of this material. Barium has about the same tendency to do this in my estimation. I have not had a great deal of experience in pot manufacture, but if you can overcome the seedy conditions with the barium, if you can overcome that tendency to laminate or segregate, you have got a glass that is far superior to any lead glass manufactured for chimney purposes.

Mr. Silverman: I would like to ask whether zinc oxide would not overcome that? There is a possibility that it may, and in the manufacture of various kinds of

ruby glass be used to displace part of the lead, I believe. Whether that is another arbitrary matter which has been handed down from generation to generation, I do not know, but it may be that zinc in displacing part of the barium would overcome that difficulty.

There is another advantage, of course, in the use of barium carbonate, in that it would eventually do away with the manufacture of glass in pots for all ordinary purposes. The present objection to flint glass is that it must be worked in the pots, and you cannot use the tank furnace. Of course, if the formation of stone persists in a barium glass, that of itself would be an objection.

Mr. Frink: In regard to the formation of stone by the use of zinc, in my opinion the formation of stone in barium glass is due to the condition of fire. Barium sulphate, when existing in any considerable quantity in barium carbonate, has a tendency to produce a stone which can be eliminated completely and without any trouble, if the temperature is maintained high enough and over a sufficient period of time. Now as to the question of the use of zinc to eliminate that condition in barium, I cannot see where it would do a particle of good. There is no comparison, in my estimation, between zinc as used in a condition of that kind, and zinc used in a condition for making ruby. When we speak of zinc in ruby we want the reducing action of zinc for something, especially when we are urging selenium. In making this ruby the use of selenium is a great trade secret. It is one of the most desirable ruby producers that we have, because its spectrum is perfect. I cannot see how zinc would effect any change whatever.

Mr. Staley: I would like to ask Mr. Frink if in the use of barium there is any tendency to sulphur, that is, was the efflorescence due to sulphur in glass noticeable, and how do you get rid of the sulphur?

Mr. Frink: There is another question that comes up. At the time I was experimenting with barium we tried it

under different conditions. It has no more tendency that I can see to sulphur than other glasses being worked in gases containing SO or SO_2. The only way to eliminate the sulphur, in my opinion, is simply to put the heat to the batch high enough and over a long enough period of time. You cannot get it in by means of the fuel, and if you get it there it is on the surface, but does not take any part during the melting period, unless it is present in the glass, until a certain point, about 1500 degrees Fahrenheit, then it will attack your glass and stay there, and all the work you can do will not take it off.

Mr. Binns: Though I have no particular experience in glass manufacture, it has occurred to me that the presence of salt cake is a source of sulphur which has to be taken into consideration, and I put it up to a glass chemist a year or so ago, and he told me that through actual analysis he found about three per cent of SO_3 in a finished glass. Does that coincide with Mr. Frink's experience?

Mr. Frink: Well, I should say not.

Mr. Binns: I would like to ask if Mr. Frink knows by analysis?

Mr. Frink: How much there is in the finished glass?

Mr. Binns: Yes.

Mr. Frink: Well, I have put some pretty diligent search for sulphur in finished glass, and yet I have been unable to find it only in such small amounts that I would say it was not near up to that quantity.

Mr. Binns: What other explanation is there for the different behavior of soda ash and salt cake but the presence of SO_3 in the glass?

Mr. Frink: That is a possible explanation, but if it small quantities and in actual fractions down to 100th of is there our search for sulphur under those conditions is pretty weak. Barium chloride will find sulphur in mighty one per cent. That is the only way to be able to find it in salt cake glass, and I have been after that almost five

years, at various times, to determine what the difference is between a salt cake and a soda ash glass, and I get identically the same content.

Mr. Binns: It has been explained to me that during the boiling subsequent to the fusion, which is considered beneficial by clearing the glass of impurities, not all the SO_3 is expelled, but a portion is left.

Mr. Frink: In answer to that point I would presume that if there is any such thing as that, when we test a specimen in the microscope, magnifying it to as high as 2000 diameters, we would likely find something of that in there, that is, it would have a tendency to refract the light ray.

Mr. Binns: I do not know why.

Mr. Frink: Well, we have a gas.

Mr. Binns: No, you do not have a gas, SO_3 is present as a sulphate.

Mr. Staley: If you add barium sulphate and sodium carbonate do you get the same sort of glass that you do with sodium sulphate and barium carbonate? Would the same ultimate analysis give the same sort of glass?

Mr. Frink: I could not answer that. I have never used barium sulphate for a sufficient length of time to say. I have known people to take a soda ash mixture and put sulphur in it, and while that has a tendency with a carbonate of any kind to produce amber glass, at the same time if melted over a long enough time it can be taken out.

Mr. Staley: One supposition that might lead to the discovery of the cause of the fluidity of the glass containing sulphur, is that if the sulphur should be there as solution of gas, it would make the glass more fluid, and the absence of the sulphur in the analysis, would mean that the gas had volatized as the glass solidified. However, it seems to me if that were the case you would have bubbles in a substance as viscous as molten glass.

Mr. Frink: I do not think that would be possible without their showing.

Mr. Orton: There is no doubt that it is possible for glass to hold sulphur in solution in the form of sulphates. I have seen analyses myself that will show the presence, besides the historic case where Seger showed the influence of sulphur on glazes, and found he could get 2.1 percent in an acid glass and 4.5 percent in a more basic glass.

My recollection is not perfectly specific, but I recall having seen a statement that a lot of "skewy" window glass was found to be high in sulphates or undecomposed salt cake. By "skewy" I mean glass which looks as if wiped with a greasy or soapy rag, and cannot be made perfectly clear and brilliant by washing. Cheap bottle glasses also show the same trouble. If the salt cake is not fully decomposed, the glass will efflorescence or break down more easily under the attack of weather.

Mr. Frink: Of course, my experience has been entirely from the practical direction in that way, taking glass from a tank furnace solely. Only a few weeks ago I had a sample sent to me, a sample of a bottle which would turn white. The efflorescence was very pronounced. The outside showed what we call a faded color. We went through those very carefully to see just where the trouble was. They brought up the same question, that they thought it was because they were using salt cake instead of soda ash. If I am correct, the sulphur content showed something like .032, very small. But the soda content was 18 percent, and therefore there was no reason why it should not show efflorescence.

ADDITIONAL NOTES ON PUGGING CLAY.

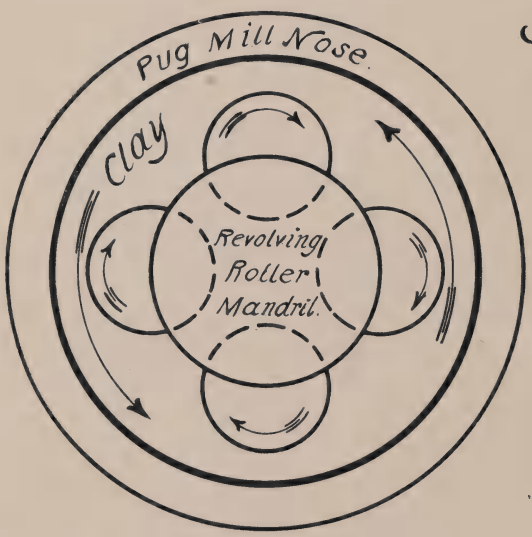
BY

GEORGE SIMCOE, Trenton, N. J.

Lately I have learned of a method employed to eliminate the laminations developed in pugging very plastic clay—such for instance as shown in Vol. XI, Trans. A. C. S. The process, as I understand it, is as follows:

In the nose of an ordinary horizontal pug mill is placed a revolving mandril, rolling the clay as it is forced from the nose of the mill thus:

TRANS. AM. CER. SOC. VOL XII. SIMCOE



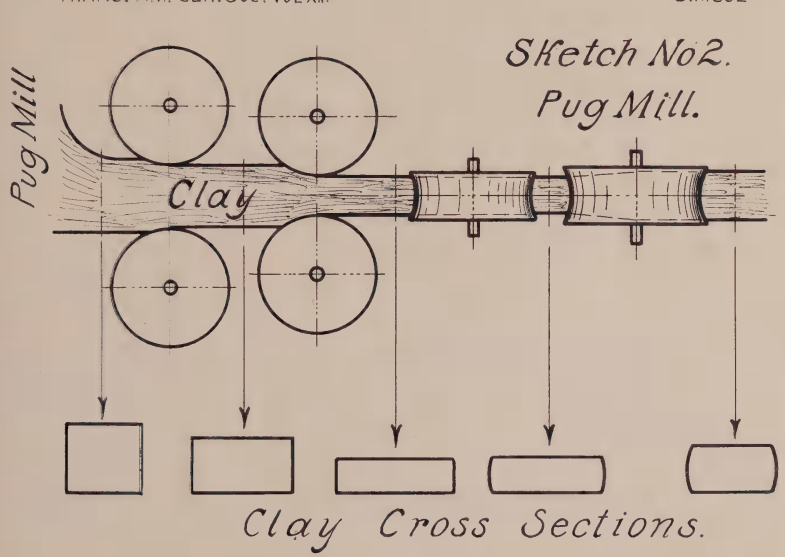
Sketch No 1.
Pug Mill.

After the tube thus formed comes out it is split and cut in to such sizes as are suited for ware.

The result of this method may be very good for the manufacture of ware not requiring a large thick piece at

the start. It is similar to the German method of rolling the clay with a rolling pin instead of batting it out. However, I have a plan to submit that I think is at least worthy of discussion, and which may be briefly described as follows:

After the clay leaves the pug mill have the bar of clay pass through three or more sets of wheels, placed one in advance of the other and applying their action to the column alternately at right angles to the clay column, thus: (See Sketch No. 2).



I would recommend the use of some form of an endless belt to convey the clay and prevent it from sticking to the wheels.

If I had the means to try the above out I would be glad to submit results but, as I feel that the proposition is entirely too expensive for me to handle, I submit it as a theory, trusting that some one of our number may see enough in it to warrant a test.

DISCUSSION.

Mr. Binns: Here is the opportunity for some of you practical clay men to come to the front. What do you think of it? Perhaps you are up against the problem of non-workable clay. I would like to ask Mr. Simcoe whether he thinks an apparatus of this kind would be beneficial in the tempering of non-plastic clay just as much as in preventing laminations in plastic clays? Our difficulty is not with the highly plastic clay, but the non-plastic clay that is extremely short to work. We want something that will make that more plastic in the tempering.

Mr. Ashley: We have with us a gentleman who has been extensively engaged in the manufacture of pug mills, and has no doubt discussed the difficulties of pugging with a good many of his customers, and I think possibly he could give us some light upon this subject,—Mr. Cawood.

Mr. Cawood: It seems to me that the ordinary trouble a man gets into in a pug mill is the fact that his laminations are entirely in the center. He never has any trouble on the outside. When he breaks a roll apart he finds the air bubbles are contained mostly in the center. To obviate that, I believe the proper thing is to have a nozzle with revolving spindle. I do not think it is necessary for that spindle to have or contain a roller. If this revolves, it gradually leads the clay to the periphery of the nozzle. All we do is to press those bubbles into the web of this tube. We have with the ordinary pug mill, first, a cylindrical roll—we have a center there which is not hard, which is like the notch in this wheel, that contains air, so that when we break it open the center part of that roll is not solid. When we put the spindle in we do away with the air in the center. But the question to my mind is whether that air is not contained in the wall of the tube that we make. It would reduce the amount of air contained there most certainly, and the probability is it would reduce it enough to make a pug mill of that kind practical. At the same time, I do not believe that we eliminate the

air altogether. The process Mr. Simcoe mentions, I believe, is practical, and I think it is somewhat similar to the process in ordinary use in France today. The process, as I understand it, is simply to have rolls operate both on the top and bottom and also on the sides of the clay, but it seems to me that, while the clay would be more thoroughly compressed, it does not do away necessarily with the air in the center—and is not that the trouble?

Another thing, it seems to me that in jollying a piece of ware or a piece of clay of irregular shape you might produce laminations in high tension ware by the overlapping of the clay when it is thrown about by the jollying tool. I do not know that to be true, but it seems to me it is, and a lamination in high tension porcelain would make it go down under test. I believe another method used in France is rolling the clay on a marble base, though I am not informed as to that.

Mr. Binns: I would like to ask Mr. Simcoe whether he would propose to have these wheels power driven or driven by the column of clay?

Mr. Simcoe: I think they would be power driven. Possibly an endless belt to help carry the clay along.

Mr. Binns: Would it not cause quite a complication of transmission to drive all those pulleys by power?

The principle I think is right as far as the kneading is concerned. The last speaker has spoken of the elimination of the air bubble, but I rather think that after the clay leaves the pug mill is the wrong time. The pug mill, with its cutting knives, is responsible for the introduction of the air bubble, and if you do not pug the clay you do not get it at all. After you have once got the air bubble in, it is extremely difficult to get it out.

I may allude further to the French rolling table of which I spoke yesterday. The process under discussion does not seem to accomplish the same work, for the reason that the French rolling table is in continuous operation for twenty minutes, and the clay passes under the rolls

repeatedly. There is no pressure from below, but the two rollers are suspended and are free to oscillate, one down hill and one up hill but not from below. Then there are two side rollers that guide the clay. This operation keeps up a continuous side pressure and treading so to speak. It is the nearest approach to foot kneading. If you could construct a series of rollers which would carry a continuous column of clay twenty minutes you would want a half mile of shop to do it in. And I do not believe a single pair of rolls working one way and the other will have very much effect on the clay column, although, at the same time, it is a move in the right direction. I believe what we want to devise is a machine that will do away altogether with the pug mill. If you can fill your pug mill with a series of rollers and prevent breaking up the clay, you will go very much farther than we have yet gone in the tempering of the comparatively non-plastic clays.

Mr. Stover: The question of kneading without tearing is one of great importance. You can frequently follow up defects evidently from tears in the ware, and there is proof that the more you knead and the more working you can give your clay and the closer you can get your clay together the stronger it is, and that is pretty clearly shown by taking up some of the pieces that you find in your scrap heap. You can go to the scrap heap with a hammer and break up pieces that have been properly joined together and cannot make the piece break following that joint. That is an evidence that the more you work plastic clay the tougher you get it. The truth is, if you start out to break up a dozen pieces the lines of fracture will cross and come in and out along where the joint is made, but very seldom does it ever follow right down the joint so as to open the joint. And if it does, it proves that the fellow did not make his joint right or else that the two pieces were not of the right temper when they were put together. Therefore, a device of this kind that could be put right in a mill that would only knead the clay and not increase the

bubbles I think would be a desirable thing for the potter. I have investigated a machine made in Germany that is sold very largely to the bread trade. I do not know if that machine is used in the clay trade, although it is used in some of the allied industries where plastic material is worked like dough.

Mr. Staley: If anyone would like to see the machine Mr. Stover speaks about, I know a firm in this town that mixes putty in a machine of that kind. I know they would be glad to show the machine in operation. It is just a trough about three feet wide and six feet long and probably three feet deep. In that there are two kneaders made out of heavy cast iron without any sharp edge, and about three or four inches wide. These crooked arms do the kneading, but there is no tearing.

It is a difficult thing to work linseed oil into white lead in order to make putty, but using this machine they get a nice even mixture. That machine will hold about a half a ton of material and, when you throw a lever, empties automatically.

Mr. Orton: Is not that the Triumph Dough Mixer?

Mr. Staley: The dough mixer may be a variation of this. These are regular putty mixers.

Mr. Stover: Their claim for this machine is that it does not tear, it works without putting in air and each arm goes in without lapping and putting in air. I have never seen it in actual clay mixing, but I have seen a machine mix graphite with some of the black German ball clay, which is a very sticky material, and the Dixon Crucible Company in Jersey City has a number of these machines mixing graphite for their crucibles. The manufacture of crucibles is very similar to some clay processes. They claim that they have gotten rid of all their air troubles.

Mr. Cawood: It seems to me that a machine of that kind makes a very good preliminary mixer, but the actual elimination of the air would be impossible because, being open, it naturally takes in air.

Mr. Stover: You cannot make crucibles when there are air bubbles in the mixture. The manufacturers of this machine said a couple of years ago they would put up a machine in the shop and we need not pay for it if it did not do the work.

Mr. Binns: I think it is up to the machine men to give us something that will do away with these troubles,—and when they do we will receive it gladly.

NOTE ON THE VISCOSITY OF CLAY SLIPS AS DETERMINED BY THE CLARK APPARATUS.[1]

BY

A. V. Bleininger and H. H. Clark, Pittsburg, Pa.

In the transactions of 1909 some experiments were described in which the Stormer viscosimeter was employed for the determination of the resistance offered by slips of various clay contents to the passage of a revolving paddle immersed in the liquid. Owing to certain inherent defects in the design of the apparatus the data are subject to variations, which render the instrument undesirable for quantitative work, as is shown clearly by the curves presented in the article mentioned, though it has a certain value for investigations of a qualitative character. As it was desired to continue the work, studying to measure the turning force more accurately brought up the idea of using electrical power and measurements. At this point the aid of Mr. H. H. Clark, electrical engineer of the Technologic Branch, was sought. It is due to his ingenuity and perseverence that the apparatus problem has been solved satisfactorily from the electrical and mechanical standpoint.

Referring again to the object of this work, it is necessary to state that any apparatus of this type does not measure viscosity in its proper physical meaning, but the resultant of a number of factors, which include the viscosity of water as modified by the dissolved salts, the mechanical resistance offered by the granular grains to the passage through the liquid and that offered by the colloidal portion, the power required to produce the mechanical motion of the suspension, etc. Since, however, the values

[1] By permission of the Director, U. S. Geological Survey.

obtained by this determination are used relatively in comparing one clay slip with another for various clay contents, and not absolutely, it seems reasonable to suppose that in the quotient some of these factors should cancel, owing to the uniform testing conditions. The device thus measures the consistency at which a certain torque is required to revolve the paddle at constant velocity. Whether this relation between content of clay and resistance to rotation is a true measure of plasticity cannot be said at this time, since the experiments made so far are too few in number. Owing to lack of funds it was impossible to carry on the work further. It seems, however, at the present time, that a value is expressed which is closely connected with plasticity as commonly understood.

As soon as it is possible to take up these experiments again it is intended to go into the question of the shape of the paddle, the use of a proper propeller screw, and similar mechanical details.

The apparatus is described in the words of Mr. Clark as follows:

This instrument consists of a paddle mounted in a square box or tub, designed to contain liquids, means for revolving the paddle and means for accurately measuring the resultant torque or turning effort.

In general, the apparatus consists of the paddle above mentioned mounted on a vertical axis, and supported upon bearings of extreme delicacy. Upon the same shaft as the paddle is mounted a hollow metallic cylinder about ½ inch in height and 4 inches in diameter, the walls being 1-32 inch thick. Within the cylinder, but supported from above so that it has no mechanical connection with the cylinder, is an electro-magnet arranged so that it can be revolved about the same axis as the cylinder.

Means are provided for revolving the magnet and for accurately observing its speed of rotation. Means are also provided for varying and observing the amount of electric current flowing through the windings of the magnet.

When the magnet is revolved and current is passed through its windings, it exerts a pull on the paddle cylinder which varies with the amount of current supplied and the difference in speed of the magnet and cylinder.

Before the instrument could be used for the purpose for which it was designed, it was necessary to determine

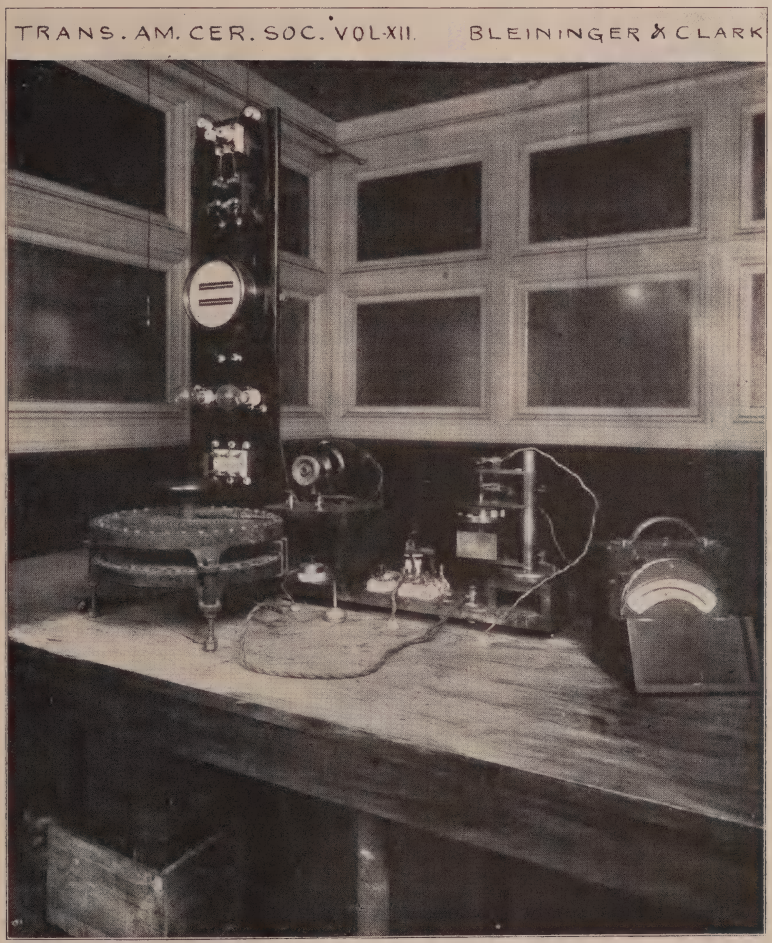


FIG. 4

by test the relation of turning effort in gram-centimeters to electric current in amperes, so that when the instrument was used for testing purposes the torque could be determined directly from observations of current strength.

In operating this instrument the liquid to be tested is placed in the box or tub before mentioned, the magnet is brought up to a predetermined speed and current is sup-

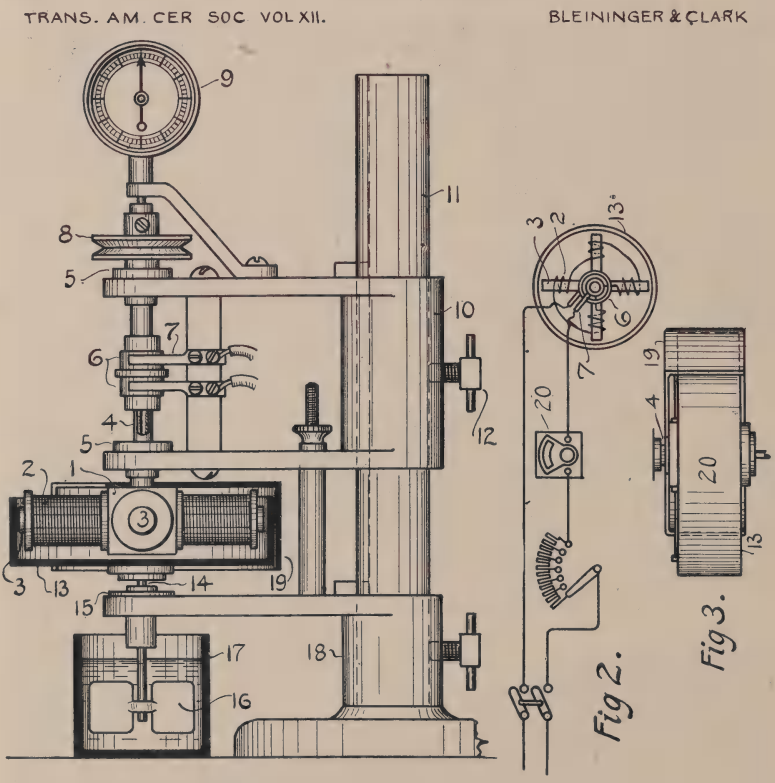


Fig 1. Fig 2. Fig 3.

plied to the magnet until the paddle revolves at the proper speed. The amount of current is noted and, from the relation of torque to current previously established and plotted in the form of a curve, the torque exerted by the

magnet on the cylinder, and conversely the retarding effect of the liquid upon the paddle, is immediately known.

Fig. 1 shows a diagrametric representation of the viscosimeter. Fig. 4 is a photograph of the machine as it was finally built for use at the Pittsburg station of the United States Geological Survey. It is obvious that there is considerable difference between these two figures, but for purposes of description Fig. 1 can be used satisfactorily. A glance at the figure will show the relation between the paddle (16) and the cylinder (13), which is mounted on the shaft of the paddle; both of them turning together in the bearing (15). The four armed electromagnet (3), diagram of connections of which is shown in figure 2, is mounted as shown directly above the cylinder and completely enclosed by it. The collector rings (6) and the brushes (7) indicate how the electric current can be supplied to the magnet, which turns on a shaft (4) in bearing (5); power being applied at the pulley (8). The speed of the magnet shaft must, of course, for any series of observations be a constant, and the tachometer (9) shows diagramatically how this speed is observed. This is not a revolution counter, but a reed frequency meter, giving instantaneous indication of the speed of revolution. It is obvious that it is necessary to know the exact speed of revolution of the paddle, and the means employed to do this are as follows:

Fig. 3 shows the outside of the cylinder (13), and the shutter (19), which cuts off exactly one-half the circumference of the cylinder and which rotates with the magnet. The outside of the cylinder is covered with dots or strips as shown, and the ratio of the width of these dots to half the circumference of the cylinder is made exactly the same as the ratio between the speed of the paddle and the speed of the magnet.

It is obvious, therefore, that when the paddle and the magnet are rotating at their respectively designed speeds, the time taken for the shutter (19) to pass the eye will be exactly the same as the time required for any one square dot of stripe to do the same thing. Consequently, when

the proper ratio of speed exists between the magnet and the paddle, the dots on the outside of the cylinder appear to stand still, and when this point is reached we know that the speed ratios are correct. If, then, the speed of the magnet as observed by the tachometer is correct, the speed of the paddle must also be correct. If the current in the magnet is then read and referred to the curve prepared by previous calibration, the exact amount of torque which is being exerted on the paddle can be determined with great accuracy.

The preparation of the clay slips for the test was the same as described in Volume XI, p. 599. The work was started with the heavier slips, which were gradually diluted. The ammeter readings were checked in each case by reversing the current through the magnet winding. Fig. 5 presents the calibration curve, showing the relation be-

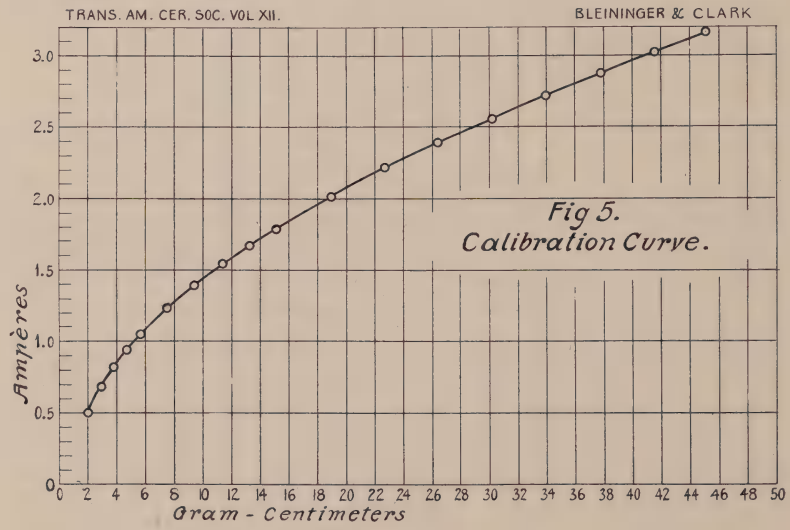


Fig 5.
Calibration Curve.

tween the amperes (storage batteries being the source of this current) and the torque in gram-centimeters as obtained by actual determination. The calibration was carried out by using a physical balance sensitive to 5 milligrams.

Four clays were tested by this method, Pike's No. 20 English ball clay, the No. 3 Tennessee ball clay (Potter's Supply Co.), the J. Poole No. 1 English China clay, con-

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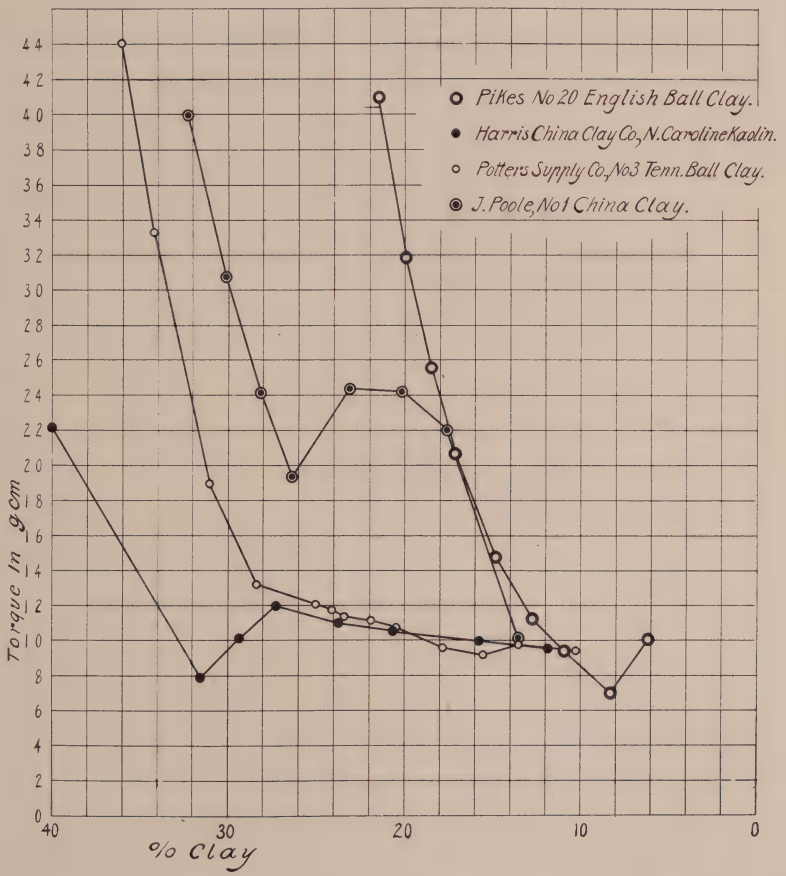
Fig 6. Relation Between Torque & Clay Percentage In Slip



sidered the best English material of its kind, of which very little is imported, and North Carolina kaolin from the Harris China Clay Co. From the curves of Fig. 6 it is seen that the order in which the clays are arranged by this test agrees practically with our conception of their rela-

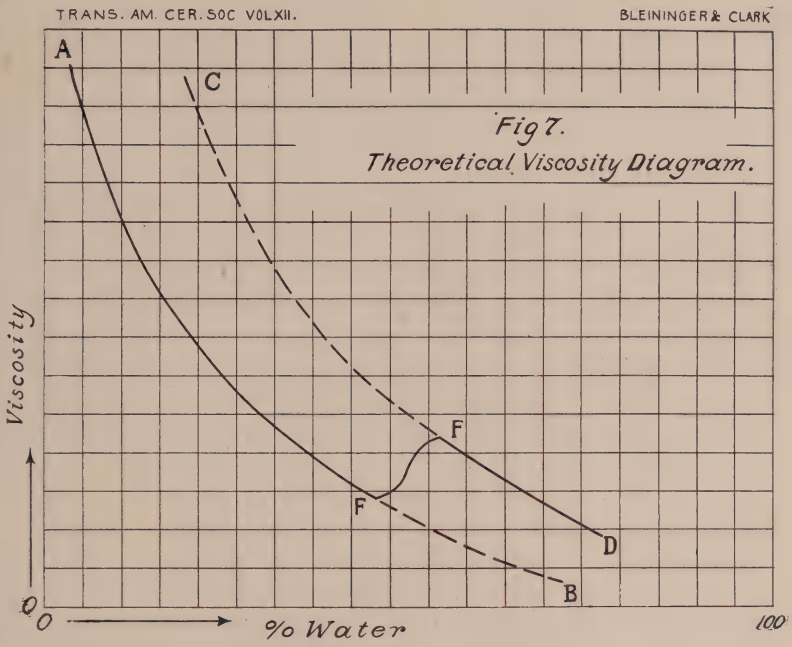
tive plasticities. Thus the same torque of 28 gram-centimeters corresponds to 33% of Tennessee ball clay, 29% of English China clay and 19% of Pike's ball clay, while evidently considerably more than 40% of North Carolina China clay would be required to bring about the same consistency.

The curves, however, show a most unexpected break in every case, which is least pronounced in the case of the Tennessee ball clay and greatest for the English China clay. The cause of this phenomena is not clear to the writers. Practically the same thing occurred in experiments carried on with lime pastes, in which it was observed that the breaks were very much more prominent for dolomitic than for high calcium limes. Mr. H. E. Ashley suggests the following explanation:

"If the quantity of matter in solution is constant, other things being equal, the viscosity will be the greater the smaller the sizes of the individual molecules.[2] Various writers have given evidence that the colloid matter of clay and other substances exists in different sizes, of which the larger may be considered polymerized.[3] Such a condensation is indicated by the fact that observed osmotic pressures of colloids are less than those calculated by electrical conductivity,[5] or by the well known fact that dyes and some other substances are frequently observed as colloidal in concentrated solutions and crystalloid in dilute solutions."[6]

"In Fig. 7 we will assume that the substance considered exists in two states of molecular aggregation, that AB represents the viscosity curve if the particles were all of the large size throughout, that CD represents the viscosity curve if the particles were all of the small size. However, on diluting the thick mixture from A, a point E is reached where the dilution is sufficient to start dissociating the large molecules into an in-

[2] Charles Henry: Comptes rend., 145, 1415 (1907).
[3] J. M. Van Bemmelen: Z. Anorg. Chemie., 42, 300 (1904).
H. E. Ashley: Min. and Sci. Press, (1909).
[5] J. Duclaux: J. Chim. Phys., Vol. 7, 405-46, (1909).
[6] S. Ya. Levites: Z. Chem. Ind. Kolloide, Vol. II, 208-15, 237-41, (1908).



creased number of smaller ones. If the dissociation occurs suddenly enough, the effect of the increased number of molecules will be an increase of viscosity. We will assume that at F the action is complete, and only the smaller molecules exist during dilution along the curve FD."

"Such cases have been noted by others. Thus Dunston and Thole[7] consider the occurrence of the maxima are indications of the existence of genuine complexes in solution; and D. E. Tsakalotos,[8] in considering the aqueous solutions of certain bases, says the maxima indicate the formation of a partly dissociated compound between the base and water."

It is proposed to study this phenomenon from the experimental standpoint, and if possible, to find an explanation for it.

[7] J. Chem. Soc., 95, 1556-61; 25, 219, (1909).
[8] Z. Phys. Chemie, 68, 32-8, (1909).

BRICK DRYING FROM AN ENGINEERING STANDPOINT, ILLUSTRATED BY SOME NOTES ON A DOUBLE DECK DRYER.

BY

DWIGHT T. FARNHAM, Seattle, Wash.

The theory of drying brick has already been pretty fully covered by Seger, and in the Transactions by Mr. Minton and others. There are, however, certain aspects of the case which present themselves when the question is approached from the engineering standpoint that are perhaps worth considering.

PART I.

In building a dryer the usual procedure is to copy some other fellow's—at least what you can see of it—and then trust to luck to get the underground part near enough right to work. This method is obviously very unsatisfactory. The ideal way would be to send a sample of your clay to a Testing Laboratory, stating at the same time the output per day desired. At the laboratory full sized brick would be made from this clay, which would be tested for their drying qualities in some such apparatus as the one devised and built at the Ohio State University. This would give the relative drying strength of your clay as compared with certain standard clays whose qualities and behavior were known. From this test the engineer, knowing how many cubic feet of air per minute at a certain temperature were required to dry a thousand standard brick, would compute from the relative position of your brick in the scale the number of hours you would require to safely dry your clay, and in a short time would notify you how many tunnels of a certain length, how large a fan, ducts, etc.,

you would need to dry your brick without loss. This would make it unnecessary to indulge in unneeded expenditure in the way of construction, and later on you would be told exactly what temperature to carry at your blower and how fast to run it.

While the data on this subject is at present rather meagre, there are certain principles which have been developed by the mining engineers and the blower people that help in the solution of the question materially. The usual waste heat dryer, which is the one considered in this paper, consists of a number of tunnels from eighty to a hundred and fifty feet in length, into which the brick are run on cars containing from four to six hundred brick each, hacked on one or two decks. The brick as they enter at the factory end contain somewhere in the neighborhood of 15% of their weight in moisture, which must be removed before the cars emerge from the kiln end of the tunnels. This is accompuished by means of a current of air varying in temperature from 150 degrees to 250 degrees Fahrenheit, and in humidity from 10% to 40% as fed in at the kiln end, and from 80 degrees to 125 degrees Fahrenheit and from 90% to 100% moisture as it is led forth from the factory end of the tunnels. The current of air is kept in motion by means of a blower which forces the air into a duct underneath the tunnels, from which it is distributed under each track and through the cars of brick.

After passing through the tunnels containing the brick this air is collected in an exhaust duct whence it is removed by a stack, a disk fan, a secondary blower, or by the force of the first blower. The supply of hot air is obtained through a duct connected with the cooling—sometimes with the burning-kilns in one of the several ways—possibly augmented by a furnace or steam coils placed near the blower. Undoubtedly the cheapest way to exhaust the saturated air is by means of a stack or stacks. The difficulty with this method is its uncertainty on account of changes in the weather. One plant located near the sea

using stacks reports a loss of 30,000 brick in a day as by no means unusual during a high wind. At other times they have trouble with insufficient draft, resulting in wet brick, and have to cut down their output. While this is an extreme case, the difficulty of obtaining uniform conditions by means of stacks is obvious.

Selection of Fan.

The disc fan is satisfactory in many ways. It requires from five to twenty horse power to operate it, but the more uniform conditions obtainable more than justify this expenditure. The secondary blower has many advocates on account of its greater positiveness than the disc fan. The first cost and the cost of installation is somewhat greater than in the case of the disc fan. The blower companies are advocating the use of a large enough primary blower to make the use of a secondary fan unnecessary. Theoretically this is all right, but it requires air tight doors on each end of the tunnels, and these are rather difficult to maintain around a brick yard.

In so far as the writer knows, the blower or paddle wheel fan is the only type of fan used at the kiln end of the dryer. There are several types on the market. The Standard Wheel, which is the type most commonly used, has the blades, which are straight or slightly curved, perpendicular to the axis of the shaft. The larger sizes--fourteen feet and over—are of usually what is known as the Giubal type, and have the blades pitched backward at an angle of about 45 degrees. This allows a more rigid construction, and is considered more satisfactory. The Sirrocco type, which has been introduced within the last few years, is rather more economical than either of the above types, the saving on the equivalent of a fourteen foot blower being about 18 H. P. The disadvantages consist in the long shaft calling for water cooled bearings, which are not readily accessible, and the necessity of twin installations where a large volume of air is desired—80,000 cubic feet per min-

ute and over. The twin installation calls for a complicated system of ducts on the kiln side of the blower, which is undesirable.

Without going into the mechanics of fan construction, which is a science in itself, certain principles suggest themselves which should be taken into consideration in selecting a fan.

I. *Efficiency.* The efficiency of a fan is the term used to indicate the ratio existing between the horse power required to operate the fan and the amount of air delivered at a certain pressure. This does not take into consideration the mechanical efficiency of the driving engine. It is the ratio between brake horse power (required to operate a fan) and the horse power output of the fan, which consists of the product of the cubic feet of air delivered per minute and the pressure or resistance reduced to foot pounds:

$$p.\ a.\ v. = U$$

$$\frac{U}{33000} \text{ equals H. P. Air}$$

$$\frac{\text{H. P. Air}}{\text{Brake H. P.}} \text{ equals Efficiency}$$

in which "p" is the unit of pressure (or resistance) in pounds per square foot, "a" is the sectional area of the airway, and "U" is the work performed by the air current. When it is stated that the efficiency of the disc fan is 30% —working under normal brickyard conditions—of the blower 45%, and of the Sirrocco 60%, then the relative work performed by each type of fan is shown in proportion to the H. P. required to operate the fan. From this it is easily seen why it is often the most economical in the end to install the more expensive outfit.

II. *Speed.* There is a limit to the speed at which a disc fan can be run and produce results. When run at more than a certain speed the air is simply cut instead of being moved. A peripheral speed of about a mile a minute

is considered the best practice. As has been shown, the efficiency of this type of fan is low, which means less air in proportion to the H. P. required to operate them than where other types are used. The limit of speed on a blower is governed by the strength of the wheel and the horse power available.

As the horse power required varies as the cube of the revolutions per minue, it is easily seen that it is cheaper to buy a larger blower than to speed up the old one beyond a certain point. To illustrate this point: Suppose you have an eleven foot blower which you are running at 150 R. P. M. This would require about 45 H. P., and at ¾ oz. pressure should give you about 80,000 cubic feet of air per minute. Suppose you are increasing your dryer and will require about 150,000 cubic feet of air per minute. You can speed up the old blower to 274 R. P. M.—taking the risk that it will stand the strain—and secure about 147,000 cubic feet of air per minute, but it will require 243 H. P. to do it; or, you can buy a fourteen foot blower, run it at 135 R. P. M. and secure it on 84 H. P. You will pay perhaps a thousand dollars for your new blower. Figure the 150 H. P. at $30.00 per H. P. year, which is low, and you will see that the new blower will take about four months to pay for itself.

Formula: H. P. varies as $(\text{R. P. M.})^3$

From the above illustration we gather also that the capacity of a blower increases directly as the R. P. M. This is important, as there would undoubtedly arise at times circumstances where only a trifle more air is needed, under which it would be justifiable to speed up the blower rather than incur the expense of a new outfit.

Formula: C. F. M. is proportional to R. P. M.

Without going into the science of fan building, which is a matter best left to the blower companies who are skilled in proportioning the blades, the intake and the outlet,

etc.—it is worth noting in general that the air pressure produced is in proportion to the diameter of the wheel, and the quantity of air delivered in proportion to the width of the wheel.

Duct Proportionment.

It has been shown that the H. P. require to operate a fan is dependent, among other factors upon the Pressure—vide p. a. v. equals U. The converse of this is that with a given fan and engine the amount of air delivered is dependent upon the pressure. As the quantity of brick dried depends upon the quantity of air delivered as well as upon its temperature, the importance of this pressure is readily seen. If you place a gauge on a water pipe two inches in diameter between a pump with a two inch discharge and a valve, the gauge will register a certain pressure. While the valve is open the water will pass the gauge at a certain velocity, (*Case A*). If you begin to close down the valve the velocity of the water coming out at the open end of the pipe will decrease but the pressure at the gauge will increase. (*Case B*). When the valve is closed tight there will be no velocity, as the water has ceased to travel past the gauge but the pressure will have increased vastly, (Static Pressure). To bring out another point: Suppose we add lengths of two inch hose to the end of the two inch pipe while the valve is open. Watching the gauge we will see a slight increase in pressure as each length of hose is added, due to the friction caused by the water having to pass over additional surface, and the water will emerge with a slightly decreasing velocity, (*Case C*). Suppose the pump is securing its water through a three inch pipe from a reservoir located close by, then it will require a certain H. P. to operate the pump. Now suppose the reservoir is removed two miles distant (*Case D*), or suppose a misguided engineer has connected the three inch suction with the reservoir by means of an inch pipe, (*Case E*). The increased work the pump would have to perform in the

first place and the loss of capacity in the second place are obvious. The general principles involved in the case of the water pump and pipes and in the behavior of a fan and heat ducts are practically the same, although the laws of hydraulics and the laws of pneumatics differ in many respects. We have in Case A, Dynamic Pressure, which consists of force converted partly into pressure and partly into velocity. The pressure and the velocity bear an inverse ratio to each other; i. e., as the pressure (on the gauge) increases (the valve being shut down) the velocity decreases, and vice versa. The product of these two factors is the measure of the force.

In mine work the weight of the atmosphere is an important factor due to the height of the air column in air ways, etc., which tends either to help out the fan or to increase its work. This is so small a factor in brick drying by mechanical draft that all Head of Air Column calculations are omitted. The effect of variations in barometric pressure, in the humidity and in the temperature of the air from the standpoint of their effect upon the velocity, pressure and power are therefore considered.

The temperature of the air does, however, make some difference in the brake horse power required to move a given quantity of air under given conditions, owing to the lesser density of the air as the temperature is increased.

Velocity. The term velocity is used to denote the speed, usually measured in feet per minute at which the air passes a given point in the air way. This velocity is uniform, and as it depends directly upon the speed of the blower it is proportionate to the cube root of the power, as will be seen later. The quantity of air passing through a given duct is found by multiplying the velocity (as registered on the dial of an anemometer) by the area of the duct expressed in square feet, which gives the cubic feet of air passing per minute.

Formula

$$V = \frac{Q}{a}$$

V is velocity; Q is quantity of air, in C. F. M.; a is sectional area of air way.

Pressure. The pressure of resistance is the sum of the forces of various kinds opposed to the flow of the air in the air ways. This resistance may be due to obstructions such as piles of refuse, broken brick, etc., which have fallen through into the duct,—to rough walls, sharp curves in the ducts, or to ill proportioned air ways. To return to the simile of the water pump—our loss in the efficiency of our system is almost as great as if we had screwed a few joints of twisted and dented pipe onto the end of our two inch discharge pipe, or as if we had put on several joints of inch pipe; the output of water in proportion to the power of the pump would be decreased, and while the gauge would show more pressure we would not get as much water. (Case E is another illustration.)

The resistance varies also in proportion to the length of the air ways (Case C and D). Theoretically, the resistance varies as the extent of the rubbing surface (the perimeter of the air-way times its length) and as the square of the velocity of the current air. It is self evident that the greater the surface traversed the greater would be the total friction and the greater the total resistance. If the velocity of the air current is doubled, each particle of air strikes in a unit of time twice the amount of resistance, rough surface, obstructions, etc., and each opposing blow is of twice the force, hence the resistance is as the square of the velocity of the current. Hence:

Formulae:

$$R = K S V^2$$

R is the dynamic resistance opposed to any ventilating pressure (such as created by a blower, etc.); K is the unit of resistance, expressed in pounds,

offered by one square foot of rubbing surface, to air moving with a velocity of one foot per minute; S is the rubbing surface of air ways exposed to the current of air, found by multiplying the perimeter by the length—expressed in square feet; V is the velocity of current in feet per minute;

$$P = p\,a$$

P is the ventilating pressure (the moving force).

p is the unit of pressure or resistance in pounds per square foot.

a is the area of air way.

The unit of ventilating pressure is expressed in "inches water gauge," and is calculated from the weight of a cubic foot of water at a temperature of 62 degrees Fahrenheit—62.355 pounds. One inch W. G. is 1/12 of this, or 5.2 pounds. "i" is inches water gauge, hence "p" equals 5.2 "i."

The importance of reducing the pressure factor when striving to secure an efficient waste heat dryer has been noted. The saving in power which can be effected in this way is large, and the saving in first cost through the avoidance of unnecessary construction is often considerable.

Formula:

$$\text{W. G. (inches)} = \frac{K\,S\,V^2}{a \times 5.2} \text{— Atkinson.}$$

This is sometimes expressed in ounces pressure per square inch, in which case .58 oz. equals 1″ W. G.

It is the factor "K" that makes exact calculation, in deciding upon a fan to meet a certain situation, difficult, as it depends directly upon the proportionment, smoothness, etc., and length of ducts. Atkinson for mine work used .000,000,021,7 as his coefficient of friction, but this has been considered too high, and the coefficient now ac-

cepted by the best engineers is .000,000,007,3, with certain corrections as follows:

One-third coefficient for air passages which are smooth, straight and regular, as the inside of galvanized steel piping used in building ventilation.

One-half coefficient for air passages which are concreted or wood lined, straight, regular and free from obstruction.

One coefficient for air passages fairly smooth, straight, unobstructed and regular in size.

One and one-half coefficient for air passages which are rough, irregular and moderately crooked.

Where the air ways are in very bad condition the resistance may be three or four times the coefficient.

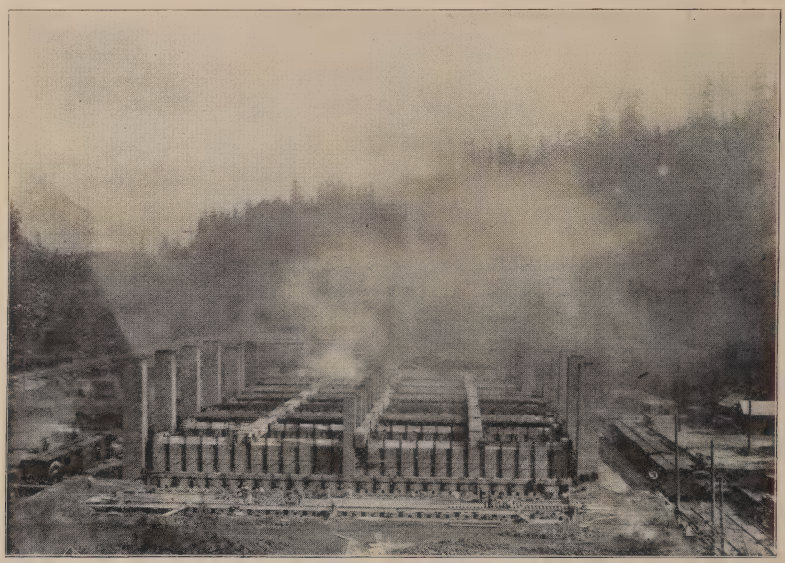
Resume. In order to save power and unnecessary dryer capacity we should have the air ways:

1. Of ample capacity throughout.
2. As short as possible.
3. Smoothly lined.
4. Without sharp bends or turns.
5. Properly proportioned.
6. Free from obstructions.

NOTE.—In proportioning the ducts it should be borne in mind that the frictional resistance is influenced by the perimiters of the ducts in question as well as the areas. In order to find, for instance, how large to make the openings leading into eighteen brick tunnels, having an opening under each track, from an underground duct containing 56 square feet, instead of dividing 56 by 36, which would give each tunnel an opening containing 1.5 square feet or 1′3″ x 1′3″, we make use of an equalization table based on the formula $n = \left(\frac{D}{d}\right)^{\frac{5}{2}}$, in which D is the diameter of the large duct, d the diameter of the smaller ducts and n the number of the smaller ducts.

PART II.

We have attempted to emphasize the necessity of observing certain rules in the installation of a fan and in the construction of heat ducts by stating briefly some of the underlying principles. During the past year the writer has had an opportunity to work out certain problems and to prove in a practical way some of these principles. The paving brick plant on which these problems were worked

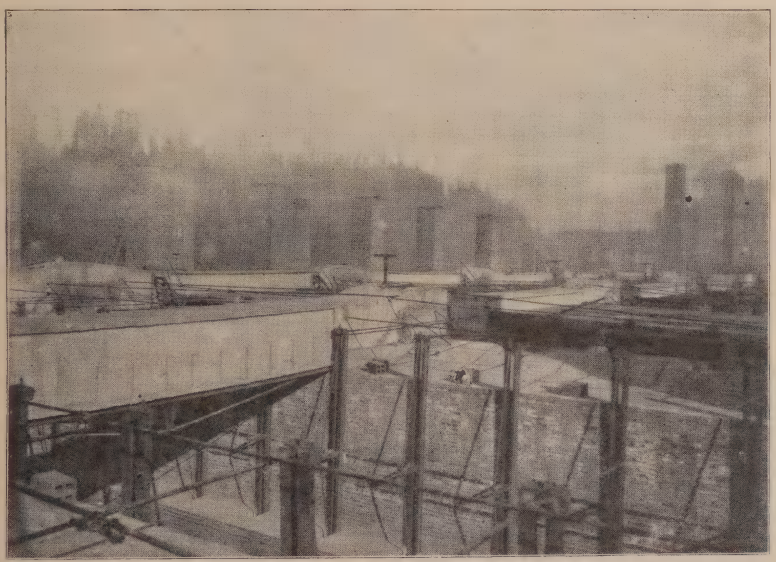


out was, until the first of the year, making and drying successfully about ninety thousand brick per day. It is now drying one hundred and fifty-six thousand, and within three months will be drying one hundred and eighty thousand 9″x2½″x4″ paving brick per day.

Kilns. At the beginning of the year there were three rectangular kilns holding 200M each, one holding 120M, five thirty-four foot round kilns holding 72M, and three rectangular kilns holding 300M, which gave the plant a

daily kiln capacity of 98,207. Since then there have been added five more 150′ rectangulars, making the daily capacity 156M, and two more are under way, which will bring the kiln capacity up to about 180M.

Drier. For ninety thousand brick the drier consisted of eighteen tunnels, 108 feet long, 6′9″ wide and 4′11″ high, each containing thirty double-deck cars, each car holding 500 brick. The eighteen tunnels with a holding

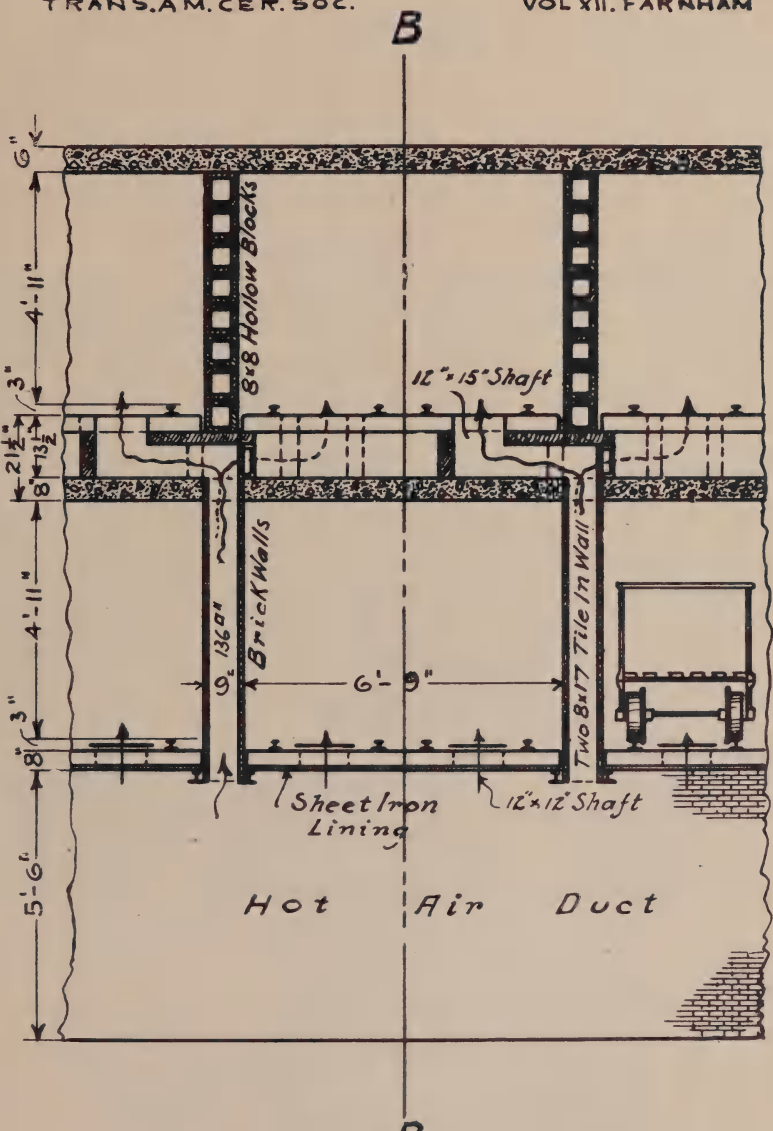


capacity of 15M brick each gave us a total holding capacity of 270,000 brick between doors. Dividing this by the three days required to dry this clay safely, we obtain a daily drying capacity of 90,000 brick per day.

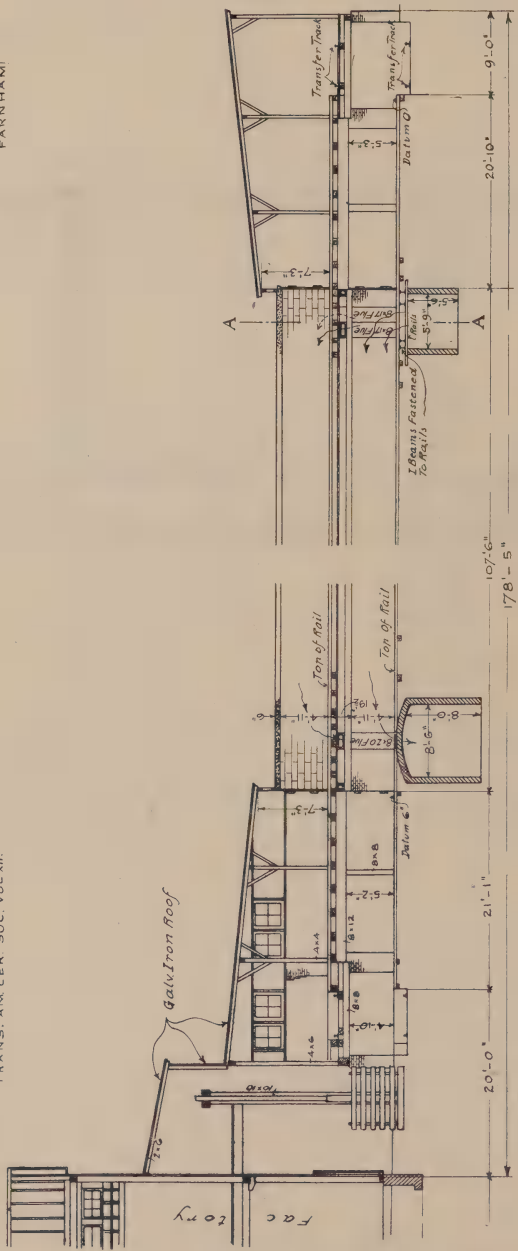
By experiment it was found that if less than three days were allowed for drying, that is, if we made more than 90,000 brick per day, by the end of the week it became necessary to set wet brick, which is not good practice either from the standpoint of high percentages of first quality ware, coal consumption, or kiln capacity economy.

If the brick remained in the dryer less than two and a half days the loss due to checked and cracked brick increased rapidly. Ordinarily all dryer loss is covered by an allowance of ten extra brick, over and above the 500 tallied, which are placed on each car. Actual count showed as high as 3,000 brick over the 2% allowance returned to the drier in a single day when less than two and one-half days was allowed for drying.

By experiment it has been determined that 240 degrees Fahrenheit in the main duct, twenty feet ahead of the blower was about as high a temperature as it was safe to carry. When the Bristol charts showed more than 240 degrees for any length of time our loss immediately went over our allowance. It was also fully demonstrated that the dryer was properly regulated by means of a series of anemometer, temperature and humidity tests which will be taken up later. Having determined that our dryer was doing all it could for us—the nature of the clay being as it was, and wishing to increase our output—it became necessary to plan more tunnels. On account of the manner in which the yard had originally been laid out it was inadvisable to add more tunnels parallel to the ones already constructed. The idea was therefore conceived of building eighteen new tunnels on top of the then existing dryer. By so constructing them it was possible to save and utilize in the upper tunnels the heat which ordinarily radiates from the top of a brick dryer, about 50% of the total radiation. At the same time the distance necessary to transfer the brick at each end of the dryer remained the same instead of being doubled. This plan was accordingly carried out, and as shown in the accompanying drawing, the lower dryer was practically duplicated in the upper dryer.


B
6"
4'-11"
3"
2 1/2"
8"
1 1/2"
4'-11"
3"
8"
5'-6"
8x8 Hollow Blocks
12"x15" Shaft
Brick Walls
9" 13 6"
6'-9"
Two 8x17 Tile In Wall
Sheet Iron Lining
12"x12" Shaft
Hot Air Duct
B

Section "A-A."


FARNHAM
TRANS. AM. CER. SOC. VOL. XII.
Transfer Track
Datum 0'
Burl Flue
Main
1 Rem. Fastened To Rail
Top of Rail
Galv. Iron Roof
Face
Longitudinal Section "B-B"

Coming from the machine the cars are elevated by means of a three ton capacity Craig-Ridgeway steam-hydraulic elevator, a device that is "fool proof," uses surprisingly little steam and seems to be practically indestructible. Its capacity is 300,000 brick per ten hours from the machine, so that we have a considerable factor of safety. A set of self-acting dogs hold the car in place on

the platform and release it automatically when the upper level is reached. In running the cars from the platform all jar is eliminated by a short section of rails fastened by a hinge at one end, the other end of which catches on the platform and rising slightly with the platform allows the car to run down a slight grade to the transfer car.

From the transfer on, the dryer duplicates the lower dryer until the ends of the kiln transfer tracks are reached. At both ends of the transfer is a gravity elevator, the

counter weights of which equal in weight the five hundred brick to be let down. This insures an easy descent with little application of the brake, the weight of the car only having to be held, and so cuts down the chances of accident. A powerful band brake restrains the descent of the 3,500 pound counter-weight as the platform returns to the upper level. A system of bolts operated by the brake lever

locks the car above while a full car is run on, and again at the bottom while the car is being run off. These precautions cut doyn the danger of accident to a minimum.

Dryer Duct System. The dryer duct system when the plant was run at 90,000 brick capacity consisted of an underground duct underneath the kiln end of the tunnels containing thirty-two square feet. In the top of this were openings averaging one square foot each which opened into the tunnels under each track. Furthermore there were

supplementary ducts at right angles to the main duct underneath each track about thirty feet long and two and one-half feet wide. The openings from these—usually four in number arranged at intervals—averaged a square foot each, making ten square feet of opening per tunnel all together.

Underneath the tunnels at the factory end was located another duct containing sixty-eight square feet near the exhaust uptake and tapering down to eighteen square feet at the eighteenth tunnel. The openings from the tunnels into this duct were 18x36 inches, but had been dampered to 10″x18″ near the exhaust fan, being graduated up to 18x36 inches at the eighteenth tunnel.

Fan Equipment. The hot air drawn from the kilns was propelled into the thirty-two foot duct by a standard blower, eleven feet in diameter run at 156 R. P. M. by a

thirty-five H. P. motor, and exhausted by means of a ten foot disc fan run at 166 R. P. M. by means of a ten H. P. motor.

Tests. Anemometer tests were made at this time with the results shown in Tables I and II. The anemometer was held in the center of one of the openings into the exhaust duct, the tunnels being nearly full of brick and the doors closed. The velocity in the main ducts was not taken at this time.

It will be observed that the dampers were changed between tests one and two, which resulted in slightly more even conditions.

	12-24-08 ANEMOMETER TEST No. 1				12-26-08 ANEMOMETER TEST No. 2			
Tunnel	2 Holes Area	Vel.	C.M.F.		Area	Vel	C.F.M.	
No. 1.....	2.5	1380	3440		2.	1200	2400	
No. 2.....	2.62	1500	3925		3.	1050	3150	
No. 3.....	2.75	930	2560		3.25	1050	3412	
No. 4.....	2.87	1050	3010		3.37	1070	3606	
No. 5.....	2.99	1130	3395		3.57	1060	3784	
No. 6.....	3.13	1070	3350		3.75	1020	3825	Cold
No. 7.....	3.24	1100	3580		2.75	1250	3437	
No. 8.....	3.38	1240	4190		2.75	1120	3080	
No. 9.....	3.51	720	2520		4.5	780	3510	
No. 10.....	3.74	650	3180		3.75	760	2850	
No. 11.....	4.01	600	2406		4.	640	2560	
No. 12.....	4.25	520	2210		4.	560	2240	Med.
No. 13.....	4.75	550	2610		4.5	600	2700	
No. 14.....	5.25	550	2900		5.	600	3000	
No. 15.....	9.	230	2070		7.5	200	1500	
No. 16.....	7.5	200	1500		6.	300	1800	
No. 17.....	7.5	300	2250		6.	400	2400	Hot
No. 18.....	9.	300	2700		6.	380	2280	
Av. per Tun	2.275	770	1439		2.10	780	1432	

After studying these tests a policy of wholesale regulation was determined upon. Arguing that with an area of thirty-six square feet in the blower duct, and with blower and exhaust fan both located near No. 1 tunnel, the short-circuiting of the air through the first tunnels—each one of which had some ten square feet of opening in

front and two and one-quarter feet at the back—was to be expected, the openings into the blower duct were closed down until they averaged about a square foot each. This gave a total opening of thirty-six square feet, which was equal to the area of the blower duct. At the same time the openings into the exhaust duct were cut down so that the average opening was about a square foot. These open-

ings were graduated, however, so that each track in No. 1 tunnel had about half a square foot, while in tunnels No. 18 it had perhaps a square foot and a half. The results were surprising. Instead of blowing where it listed the air went where it was wanted. The tunnels dried the brick evenly and dried more brick.

It was found that much better results could be obtained by introducing all the air at one place in a tunnel,

and the flues underneath the tracks were accordingly bricked up. It seemed that with a tender clay there was much less loss when the dry hot air, as it came from the duct, came in contact with the dryest brick first. It could not injure these, but did absorb a little moisture, and absorbing a little more, as it passed on, by the time it struck the really tender brick half way up the tunnel, it was

carrying sufficient moisture to reduce its absorbing power considerably. As a result these brick were not cracked but were dried enough to prepare them for the next stage a little further on. When the air was introduced thirty feet up the tunnel also, it struck the brick, while still tender and with the shrinkage only partly out of them, full force with its absorptiveness unimpaired and many cracked brick resulted.

In regulating, the dampering was done at the exhaust

end of the tunnels because it was possible to close the openings there more easily and because the heat made it impossible to take anemometer readings at the front end. The writer's theory has been that permanent regulation—to offset distance from the exhaust fan, to prevent short circuiting, etc.—should be done at the exhaust end, dampers being used over the openings from the blower duct only when for some reason it becomes necessary to close off a tunnel entirely. The disadvantages of attempting to operate dampers at both ends, and at the same time to attempt any systematic regulation, are manifest.

Waste Heat Duct. The underground duct from the kilns had been installed for a plant of about 50,000 daily capacity. At the time of Test I Overhead Duct No. 1 had not been constructed nor Section A and B. Overhead Duct II had an area of 6.2 square feet, Center Down-take an

area of 8.7 square feet, and the underground old South Duct averaged six square feet. The North Duct, which has since become the Main Duct, began at the North Downtake (12.5 square feet) which was fed by Overhead Duct III (9.9 sq. ft.). Section C averaged about seven square feet, Section D 9.5 square feet, Section E 14 square feet, Section F 17.2 square feet, Section G 21 square feet.

As has been previously stated, it was found after it had been proved that the dryer was properly regulated, that more tunnels were necessary in order to increase the dryer capacity. The tunnels were constructed as described. It was thought best to have the upper dryer entirely independent of the lower dryer. The flues to conduct the heat from the blower duct to each individual track were therefore constructed in the walls of the lower dryer, being made of flue lining, so that each track had an opening of 108 square inches or .75 square feet. These would have been made larger but for certain constructional difficulties encountered which seemed insurmountable. The same arrangement was made at the exhaust end of the tunnels. The policy of dampering at the exhaust end of the tunnels was continued as in the lower tunnels. As soon as the upper dryer was completed and two-thirds full of brick an anemometer test was run, which resulted as follows:

ANEMOMETER TEST No. 3.

6-24-09 Both Holes Each Tunnel.

	Uprer Dryer			Lower Dr\er		
Tunnel	Area Sq. Ft.	Vel.	C. F. M	Area Sq. Ft.	Vel.	C. F. M.
No. 1	1.285	730	935	.75	1570	1177
	1.45	710	1030	.75	1510	1133
No. 2	1.28	770	986	.75	1490	1118
	1.28	790	1011	.75	1510	1133
No. 3	1.28	730	935	.75	1730	1298
	1.28	710	910	.75	1690	1269
No. 4	1.28	730	935	.875	1590	1392
	1.28	750	960	.875	1590	1392
No. 5	1.28	790	1011	.75	1490	1118
	1.28	790	1011	.75	1450	1090
No. 6	1.20	770	925	.75	1550	1162
	1.28	770	986	.75	1550	1162
No. 7	1.28	770	986	.875	1530	1340
	1.28	810	1038	.75	1630	1222
No. 8	1.28	870	1115	.75	1550	1162
	1.28	590	756	.75	1650	1238
No. 9	1.28	790	1011	2.12	800	1695
	1.28	550	704	1.451	910	1320
No. 10	1.38	550	759	.875	870	761
	1.38	470	648	.75	930	697
No. 11	1.23	610	751	.75	540	405
	1.25	570	713	1.03	720	741
No. 12	1.28	550	704	.75	670	503
	1.45	490	711	.96	570	547
No. 13	1.20	530	636	1.00	750	750
	1.28	510	653	1.00	780	780
No. 14	....	...	...	1.65	570	941
	....	...	...	1.33	670	891
No. 15	....	...	...	2.01	570	1146
	....	...	...	1.72	530	911
No. 16	....	...	...	2.19	470	1030
	....	...	...	2.19	480	1052
No. 17	....	...	...	2.19	430	942
	....	...	...	2.19	390	855
No. 18	....	...	...	2.84	310	881
	....	...	...	2.84	350	995
Average per track..	1.292	.682	878.5	1.227	1038	1030

It will be noted that the G. F. M. per tunnel is more nearly uniform than in Tests I and II.

Tunnel No. 8, lower, has a total opening of 1.5 square feet and secures 2,400 C. F. M., while No. 9 has an opening of 3.57 square feet and secures 3,015 C. F. M. The blower duct is constricted between the two tunnels which tends to increase the pressure and, hence, the C. F. M. delivered to No. 8, No. 9 being robbed in proportion. From this test it was seen that while the top dryer averaged 1.29 square feet of opening per track it averaged only 878.5 C. F. M., while the lower dryer with 1.22 square feet averaged 1,030 C. F. M. The deduction, of course, was that the frictional resistance encountered by the air passing to the upper dryer reduced its velocity. As the upper flues could not be opened any wider the lower dryer flues were each closed off twelve percent. The increase in the daily output, which had been curtailed by damp brick, was immediately apparent, amounting to perhaps four thousand a day, and the brick were pulled dry from the upper dryer as well as from the lower dryer, which had not been the case before.

New Waste Heat Duct. It was found that the dryer after being regulated would dry about 135,000 brick per day, on an average, so that further changes were necessary in order to increase the dryer capacity. The blower in use had an intake of thirty-eight square feet. The main underground waste heat duct had an area of twenty-one square feet. Referring back to our simile of the water pump we had here a case of a one inch pipe coupled onto a three inch suction. It was therefore decided to install a new underground waste heat system.

Area of Underground Duct. It was figured out that there would not often be more than two 150′ kilns on the dryer at one time. We had been able to cool this type of kiln in the past in the allotted six days through twelve square feet of opening in each crown, so that we felt safe in establishing as a standard six square feet per 100,000 brick to be cooled. We accordingly made three openings

1′x6′ in the top of each long kiln holding 300M brick. This gave us an opportunity to cool three kilns at the old rate or, if we thought best, we could cool the two kilns more rapidly. Three overhead ducts were constructed over the tops of the long kilns with an average area of twelve square feet each. The South Downtake communicated with a duct (A) containing sixteen square feet, which took care of two-thirds of No. 10 kiln (72M brick—6 openings or four square feet). This in turn opened into a duct (B) containing thirty square feet, which took care of the twelve square feet of the center overhead duct and four square feet from Kiln No. 11. Section C took care of this duct and the North Overhead Duct, and so contains forty-two square feet.

NOTE.—Each enlargement contains slightly less than the sum of the previous areas and the area of the added kiln connections. This matter was mentioned in connection with the equalization table.

Section D contains forty-eight square feet, Section E fifty-four square feet, Section F fifty-four square feet and Section G fifty-nine and one-half square feet, the general rule being followed of taking care of each 100M brick with six square feet of duct. This necessitated, of course, figuring out how many at a time of each group of kilns would be cooling at a time, as illustrated in the case of 150′ kilns.

Construction. The duct was very carefully constructed in order to keep out the water during flood season. The soil consisted mostly of sand and gravel, long dried by the heat from the kiln bottoms. Careful timbering was therefore necessary, as the duct ran within a few inches of the kiln foundations in many places.

The method was briefly as follows: Square frames were made of 6x6 timbers and placed about six feet apart crosswise of the proposed ditch. To these were nailed 2″ planks parallel to the ditch. Usually about three frames comprised a unit. The earth was dug out from between

the two inch planks and thrown outside of them. In this way the cribs were lowered, being urged now and then with a maul until the desired depth was reached. The bottom of the trench was paved with from two to four courses of hard burned brick laid in a one-to-one mixture of cement and sand. The walls of the duct were erected on this pavement of 8″x8″ hollow blocks, backed up with from four and one-half to thirteen inches of brick, plastered on the outside with three-quarter inches of cement. The inside of the duct was lined with three-quarter inches of cement on the bottom and also for about two feet up the sides. This gave a smooth surface, helped keep out the water and gave us a chance to maintain a uniform grade to the two sumps, which were constructed at opposite ends of the duct and extended two feet below its lowest portion. The duct was covered with a 6″, one to five mixture, concrete slab reinforced with one-quarter inch electrically welded reinforcing netting. Every four feet the duct was crossed with a twelve pound rail. Notches were left in the top of the wall which received a portion of the slab and tied it to the wall. A concrete slab five and a half inches thick, reinforced with one-quarter inch netting on an eight foot span will support a concentrated load of 4,000 lbs. with a factor of safety of two. It is also guaranteed to stand 1700 degrees F when made one to six mixture. A cart of coal containing a ton, weighing perhaps 3,500 pounds, distributed at two points, is about the heaviest thing that crosses a waste heat duct, so that our construction allowed at least a good factor of safety. It required sixteen days to complete this duct from the time the excavation was begun. Nine days later it was thrown into commission and has been in use ever since.

The effect of this was immediate. The C. F. M. in the blower duct increased from 57,000 to 83,000, or about 44%, and we were able to dry 155M brick per day instead of the previous limit of 135M. The anemometer test made of the previous limit of 135M. The anemometer test, made about two weeks after the duct was thrown into commission, follows:

ANEMOMETER TEST No. 4.

8-26-09, P. M.

	Upper Dryer			Lower Dryer		
Tunnel	Area Sq. Ft.	Vel.	C. F. M.	Area Sq. Ft.	Vel.	C. F. M.
No. 1	1.28	750	960	.675	1630	1100
	1.28	790	1012	.825	1570	1296
No. 2	1.28	910	1174	.787	1630	1282
	1.28	730	935	.825	1830	1510
No. 3	1.28	650	832	.901	1510	1360
	1.28	810	1037	.826	1770	1462
No. 4	1.28	670	858	.750	1570	1178
	1.28	730	935	.750	1750	1312
No. 5	1.28	870	1112	.675	1790	1208
	1.28	830	1062	.675	1790	1208
No. 6	1.28	830	1062	1.125	1630	1835
	1.28	750	960	.901	1750	1577
No. 7	1.28	770	986	.675	1330	898
	1.28	810	1037	.750	1630	1222
No. 8	1.28	810	1037	.750	1630	1222
	1.28	810	1037	.750	1770	1328
No. 9	1.28	630	806	.778	950	738
	1.28	580	743	.687	990	680
No. 10	1.28	630	806	.825	1370	1130
	1.28	650	832	.825	1270	1048
No. 11	1.28	590	756	.70	1310	917
	1.28	650	832	.791	1310	1036
No. 12	1.28	570	730	.687	1150	790
	1.28	570	730	.500	1250	626
No. 13	1.28	650	832	.625	1190	744
	1.28	590	756	.496	1270	630
No. 14	1.28	570	730	.531	1290	686
	1.28	650	832	.563	1370	772
No. 15	1.28	650	832	.483	830	401
	1.28	570	730	.508	910	462
No. 16	1.28	510	653	.625	1030	644
	1.28	510	653	.583	1110	648
No. 17	1.28	410	525	.75	930	697
	1.28	470	602	.666	1050	700
No. 18	1.28	310	397	.87	1070	932
	1.28	450	577	.785	950	746
Average	1.28	...	872	.692	....	996

Month	Date	Day	M Made	M Set	Duct Temp.	T. Upp'r Dry'r Operated	C. F. M. Main Duct	Cond t Brick		Top Temp.		Bott m Temp.	
								Top Dryer	Bot. Dryer	Front	Back	Front	Back
June	1	Tues.											
"	2	Wed.	94.8	103.6	240°	0							
"	3	Thur.	95.2	103.8	"	0							
"	4	Fri.	97.6	88.3	"	0							
"	5	Sat.	66.7	90.3	"	0							
"	6	Sun.			"	0							
"	7	Mon.	101.4	85.2	"	0							
"	8	Tues.	100	103	"	0							
"	9	Wed.	116.5	102.8	"	0							
"	10	Thur.	124	103.1	"	0			Wet				
"	11	Fri.	99	102.7	"	0			"				
"	12	Sat.	106	100.6	"	0			"				
"	13	Sun.			"	0							
"	14	Mon.	130	102.6	"	5			Dry				
"	15	Tues.	130	100.6	"	5			"				
"	16	Wed.	120.5	102.5	"	8			Damp				
"	17	Thur.	133	102	"	8			Wet				
"	18	Fri.	119	90	"	8			"				
"	19	Sat.	106	119	"	8		Wet	"				
"	20	Sun.			"	8							
"	21	Mon.	110.8	119	250	11		Dry	Dry				
"	22	Tues.	127.3	119	"	11		"	"	177°F	91°F	163°F	96°F
"	23	Wed	135	119.4	"	11		Wet	"	171	84	162	89
"	24	Thur.	131	117.5	260	12		"	Wet	164	100	154	93
"	25	Fri.	116	115.2	"	13	56100	"	"	165	92	149	96
"	26	Sat.	110.6	114.2	"	14		Damp	Damp	170	97	142	92
"	27	Sun			"	14							
"	28	Mon.	128	132.6	270	14		Dry	Dry	163	90	162	98
"	29	Tues.	131	135.3	280	14		"	"	178	91	179	101
"	30	Wed	132.1	134	"	14		Damp	Damp	193	93	175	101
July	1	Thur.	122	125.2	"	14		Wet	Wet	160	104	162	96
"	2	Fri.	130.2	136.4	275	14	54100	"	"	170	102	145	92
"	3	Sat			260	14		"	"				
"	4	Sun			"	14							
"	5	Mon.			"	14		Dry	Dry				
"	6	Tues.	135.2	135.8	"	14		"	"				
"	7	Wed.	130.4	137.1	270	14	57800	"	"	160	92	170	110
"	8	Thur.	134.6	138.9	280	14		"	"	163	95	160	103
"	9	Fri.	136.1	138.7	"	14		"	"	154	94	170	100
"	10	Sat.	127	136.7	260	14		"	"	150	98	160	98
"	11	Sun.			"	14							
"	12	Mon.	137.1	147.5	280	12		Dry	Dry	160	90	165	98
"	13	Tues.	145.1	138.2	"	12		"	"	145	88	160	100
"	14	Wed.	150.1	136.4	"	12		"	"	148	88	150	95
"	15	Thur.	145.1	139	"	12		Damp	"	160	85	165	95
"	16	Fri	121.4	110	"	12		Wet	Damp	160	78	165	95
"	17	Sat.	139.4	130.1	"	13	43584	"	Wet				
"	18	Sun.			"	13							
"	19	Mon.	150.3	136.1	"	14		Damp	Dry				
"	20	Tues.	151	139	"	14		Wet	Wet				
"	21	Wed.	152	138.3	"	15		"	"				
"	22	Thur.	148	137.9	"	15		"	"				
"	23	Fri.	152.5	135.5	275	16	52992 50880 54460	"	"	130	84	120	85

General Observations	BLOWER DATA				Exhaust Disc Data			Days Dried
	R. P. M.	Vel. Air	Shutter Open	Kilns on W. H. Duct Condition—Portion Open	R. P. M.	Vel. Air	C. F. M.	
Holiday								3
No loss in June or July above ten per car.								3
								3
								3
								4
								3
								3
								3
Steam Hyd. Elev. In Commission								3
								4
Wood Fire								3
Pulling only								3
Lower								3
Tunnels								3
								3
								4
								3
								3
See Ther. Test 1								3
See Ann. Test 3 See Ther Test 2	146	1750		16, 15, 1	165	640	43520	3
See Ther. Test 3								3
								3
Decreased Lower								3.8
Ex. open 12%								3.8
								3.7
	155	1690		13, 7	164	835	56780	
				Temperature and humidity				
				in open air,				
				wet 62°, dry 75°, humidity 47				
	156	1804		3, 9, 10 8, 14	200	924	62832	
				wet 60°, dry 70°, humidity 55.				
				wet 57°, dry 68°, humidity 55.				
				wet 60°, dry 70°, humidity 55				
Began Excav New W. H. Duct.								
	148	1362		5, 2	204	830	56440	
Wood Fire								
" "								
" "								
" "								
" "								
	156	1656	4⁰′	1, 9 a. m.				
" "	145	1590	4⁰′	1, 12:50 p. m.				
	148	1700	4⁰′	1, 4:45 p. m	200	896	60928	

Month	Date	Day	M Made	M Set	Duct Temp	T Upp'r Dry'r Operated	C. F. M. Blower Duct	Condit Brick		Top Temp.		Bottom Temp.	
								Top Dryer	Bot. Dryer	Front	Back	Front	Back
July	24	Sat.	134.8	138.1	275	16	59200	Wet	Wet	160	84	160	94
"	25	Sun	.....	.....	260	16	.....	.....	.....	.....	.....	.....	.....
"	26	Mon.	150	138	250	17	.....	Dry	Dry	150	87	158	93
"	27	Tues.	135	130.3	275	17	.....	"	"	167	92	165	86
"	28	Wed.	153.5	134.3	280	18	.....	"	"	160	92	175	102
"	29	Thur.	134 9	139.5	280	18	.....	Damp	Damp	168	92	167	102
"	30	Fri.	134	136.7	280	18	62400	Wet	Wet	170	94	170	94
"	31	Sat.	132	134	275	18	.....	"	"	.....	.....	.....	.....
Aug	1	Sun	.....	.....	280	18	.....	.....	.....	.....	.....	.....	.....
"	2	Mon.	133.4	137.6	260	18	.....	Damp	Dry	.....	.....	150	112
"	3	Tues.	136.5	137.9	289	18	.....	"	"	170	90	155	106
"	4	Wed	133.5	131.4	280	18	.....	"	"	170	92	165	95
"	5	Thur.	135	138.3	275	18	.....	Wet	"	.....	.....	.....	.....
"	6	Fri.	139	135.8	260	18	.....	"	"	.....	.....	.....	.....
"	7	Sat.	.....	.....	275	18	.....	"	"	185	90	164	94
"	8	Sun.	.....	.....	280	18	.....	.....	.....	.....	.....	.....	.....
"	9	Mon.	135	136.5	240	18	84456	Dry	Dry	215	96	180	105
"	10	Tues.	136.7	139.1	240	18	87520	"	"	205	98	174	100
"	11	Wed.	140.5	142	230	18	96638	"	"	192	102	182	108
"	12	Thur.	139	142	240	18	87670 / 93200	"	"	190	92	188	102
"	13	Fri.	136 2	145	240	18	87819	"	"	192	98	180	100
"	14	Sat.	146	153	240	18	.....	.....	.....	180	95	180	105
"	15	Sun.	.....	.....	240	18	.....	Dry	Dry	.....	.....	.....	.....
"	16	Mon	146	152.7	235	18	86773	"	"	176	94	174	107
"	17	Tues.	152.2	152.4	240	18	93788	"	"	189	93	175	106
"	18	Wed	147.5	151.2	245	18	93798	"	"	174	97	174	106
"	19	Thur	147 5	152.6	250	18	93574	S. D'p	"	188	97	196	108
"	20	Fri	147.4	152.8	240	18	97610	" "	"	186	92	188	107
"	21	Sat.	125.2	152.0	240	18	.....	Dry	"	205	92	181	102
"	22	Sun.	.....	.....	.....	18	.....	.....	.....	.....	.....	.....	.....
"	23	Mon	144.3	154	245	18	102917	Dry	Dry	186	94	188	108
"	24	Tues.	149	152.5	250	18	93200	"	"	201	99	204	109
"	25	Wed	149 5	147.0	245	18	90211	"	"	196	94	201	110
"	26	Thur.	150.3	153.6	250	18	95443	"	"	.....	.....	.....	.....
"	27	Fri.	142.8	156 9	250	18	.....	"	"	.....	.....	.....	.....
"	28	Sat.	136.3	150.9	240	18	.....	Damp	"	.....	.....	.....	.....
"	29	Sun.	.....	.....	240	18	.....	.....	.....	.....	.....	.....	.....
"	30	Mon.	153.1	157.1	250	18	89613	Dry	Dry	172	97	189	102
"	31	Tues.	150	153 8	250	18	81092	Damp	"	187	99	180	111
Sept.	1	Wed.	153 4	137.9	250	18	83783	"	"	191	99	193	114
"	2	Thur	147.5	137.9	250	18	86474	"	"	180	98	191	113
"	3	Fri.	134.9	132 9	245	18	87147	"	"	175	93	184	104
"	4	Sat.	123.5	135.9	245	18	85951	Wet	"	178	91	177	111
"	5	Sun.	.....	.....	245	18	.....	.....	.....	.....	.....	.....	.....
"	6	Mon	.....	....	245	18	.....	.....	...	....	.....	.....	.....
"	7	Tues.	147.7	158	230	18	93574	Dry	Dry	196	110	188	138
"	8	Wed.	144 4	143 9	215	18	112408	"	"	191	105	188	135
"	9	Thur.	144	154 5	.....	18	93574	"	"	180	92	181	110
"	10	Fri	147	152.4	.....	18	86922	"	"	.....	.....	.....	.....

General Observations	BLOWER DATA			Kilns on W. H Duct. Conditions—Port on Open	Exhaust Disc Data		
	R.P.M.	Vel Air	Shutter Open		R.P.M.	Vel Air	C.F.M.
Wood Fire	156	1850	4″+	1, 12:45 p. m.			
" "							
" "							
" "							
" "							
" "							
" "	156	1950	6″	3:35 p. m.			
Concrete Fin.							
Tunnels Pulled Unevenly				Wood fire in furnace			
				" " " "			
				" " " "			
				" " " "			
Blower Duct Enlarged 32° to 37°				" " " "			
				13, 18			
				13, 14, 6, 12			
New Waste H. Duct used	156	2260	1″				
	156	2342	2″	18, 13, $\frac{1}{2}$14	200	904	61472
	152	2563	4″	13, $\frac{2}{3}$6, $\frac{1}{2}$14, $\frac{1}{3}$12	200	930	63240
	152	2346	0″	13, $\frac{2}{3}$6, $\frac{1}{2}$14, 12			
	153	2494	6.5″	$\frac{1}{2}$14, 6, $\frac{1}{2}$19, 12			
	152	2350	1″	2, 12, 19			
				2, 17, 19			
	152	2322	2.5″	19 c, 17 h, $\frac{1}{2}$ 2 c			
	153	2590	0.	19 c, 17 h, 2 c, $\frac{1}{2}$ 3 h			
	153	2510	0.	19 c, 17 c, 2 c, $\frac{1}{2}$ 3 h			
	153	2504	0.	5 h, $\frac{2}{3}$ 11 h, 17 c, 2 c, $\frac{1}{2}$ 3 c			
	152	2612	0	5 h, $\frac{2}{3}$ 11 h, 17 c, 2 c, 3 c			
				1, 4, 5, 7, 16			
	152	2754	0	1 h, 4 c, $\frac{1}{3}$ 5 c, $\frac{1}{2}$ 7 h, $\frac{1}{3}$ 16 h			
	152	2494	.5″	1 c, 4 h, 16 h			
See Ther. Test 5	152	2414	0.	1 c, 4 c, 16 h, 7 h			
See Ann. Test 4	152	2554	.5″	1 c, 7 c, 16 c, 4 c	195	726	49368
				1 7, 9, 16			
Top pulled heavy				9, 15, 16			
Top pulled heavy	153	2398	0.	9 c, 15 h, 16 c			
" " "	152	2170	0.	18 (600°), 15 (550°), 16 c			
	153	2240	2″	15 (450°), 18 (450°), 8 (550°) 16 c			
Blower shut down 7 hrs.	152	2314	0.	$\frac{2}{3}$ 8 (500°), $\frac{2}{3}$ 18 (350°), $\frac{1}{2}$ 15 (470°)			
	152	2332	0.	$\frac{2}{3}$ 8 (380°), $\frac{3}{4}$ 10 (560°), $\frac{1}{3}$ 12 (730°) $\frac{1}{2}$ 15 (260°), $\frac{1}{3}$ 18 (390°)			
	152	2300	0.	15 (120°), $\frac{3}{4}$ 10 (430°), $\frac{2}{3}$ 8 (240°), 18 (300°), $\frac{1}{3}$ 12 (640°)			
No loss in							
Aug. or							
Sept. above	152	2509	0.	$\frac{1}{3}$ 13 (570°), $\frac{1}{2}$ 12 (170°), 8 (60°), $\frac{2}{3}$ 10 (170°), 18 c			
ten per car	152	3008	16″	6 (320°), 10 c, 12 (40°), 13 (410°), 14 (660°), 18 c, 8 c			
	1 2	2504	4″	14 (630°), 6 (240°) 13 (270°), 12 (30°). 8 c 10 (20°), 18 c			

This closes the record of constructional changes to date. Next month we will install the fourteen foot blower for which the duct was constructed, which will give us somewhere in the neighborhood of 150,000 C. F. M. The calendar contains the data from which a large portion of the foregoing conclusions were drawn:

I. June 25th. As a result of the anemometer test made on this date the exhaust openings in the lower dryer were closed off twelve percent, as previously noted, and the temperature in the lower duct raised from 240 degrees to 280 degrees. This was considered safe as the extra tunnels thrown into commission retarded the progress of the brick through the tunnels, giving them nearly four days to reach the hot end. It was figured that the high moisture carrying capacity of the air at a higher temperature would in a measure offset the lower quantity of air received by each tunnel, and at the same time, since the water would be removed from each individual brick no faster, there would be no great loss from checked brick. In this we were justified, and from 260 to 280 degrees were carried until the new waste heat duct was thrown in.

II. The difference in temperature between the air in the blower duct and in the front of the tunnels directly over the duct the writer is inclined to lay to the effect of the rapid evaporation taking place in the tunnels, and possibly to some extent to the lower temperature on the outside of the door. The hygrometer was placed on the floor of the tunnel leaning against a car of brick, and the doors closed for about five minutes. Temperatures taken directly in the openings from the blower duct to the tunnel showed almost the same temperature as registered on the Bristol, so the fall in the temperature took place immediately after the air emerged into the tunnel.

III. The disc fan was speeded up from 164 to 200 R. P. M. on July 7th. There is considerable variation in the air delivered by this fan. On the 7th it gives 62,832 C. F. M. (Blower 57,800). On the 17th 56,440 C. F. M.

(Blower 43,584). On the 16th 60,928 C. F. M. (Blower 54,400). The amount delivered by the disc seems to vary with the amount of air delivered by the blower, which is what one would expect.

IV. The variation in the amount of air delivered by the blower varies pretty consistently with the distance traversed by the air from the kilns.

July 2, 54,100 C. F. M., kilns cooled remote.
July 7, 57,800 C. F. M., kilns cooled near.
Aug. 9, 84,456 C. F. M., kilns cooled remote.
Aug. 23, 102,917 C. F. M., kilns cooled near.

The amount of air is also affected by the amount the shutter is open and by the number of kilns on the duct. The greatest amount of air delivered after the enlargement of the duct was 112,408 cubic feet when a large number of kilns were on and the shutter opened sixteen square feet. The least noted was 81,092 C. F. M. with the shutter closed and with kilns No. 15, No. 16 and No. 18 on—few and all remote.

Temperature Tests. As the anemometer tests involved considerable trouble, they were taken only occasionally when it seemed necessary to materially change the policy of handling the dryer. One test was in most cases sufficient to locate the trouble beyond question. It would have been interesting to have had anemometer tests after the corrections were made, but as a second test was not necessary it was not taken.

In order to keep the dryer in balance under ordinary conditions a daily test was made with the hygrometer, examples of which follow:

THERMOMETER TEST No. 1. 6-24-09.

Lower Dryer						Upper Dryer						Tunnel No.
Front			Back			Front			Back			
Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	
96	138	27	88	90	100	96	164	12	93	106	77	1
101	156	20	84	88	90	98	186	3	92	104	72	2
99	144	28	88	93	98	96	166	11	89	100	57	3
90	116	43	86	92	84	94	162	13	93	105	58	4
100	144	28	91	95	91	96	164	13	92	104	72	5
98	130	34	88	94	80	95	168	10	92	100	80	6
100	168	14	97	100	90	101	193	0	94	104	77	7
100	164	16	92	98	80	96	158	16	92	100	80	8
108	167	20	90	91	100	100	167	14	91	99	80	9
112	172	20	92	98	80	94	162	13	93	98	90	10
112	188	11	92	97	80	101	181	5	86	98	74	11
106	164	19	92	94	92	101	160	19	92	96	92	12
108	166	20	89	96	88	101	158	19	92	98	90	13
106	152	28	92	94	92	....	.....	.....	....	.....	.....	14
101	164	16	87	90	90	....	.....	.....	....	.....	.....	15
106	140	35	87	90	90	....	.....	.....	....	.....	.....	16
101	139	32	84	86	94	....	.....	.....	....	.....	.....	17
100	152	24	80	86	80	....	.....	.....	....	.....	.....	18
Average	153.5	24.1	....	93.3	88.8	....	169	11.38	....	101	76.8	....

Average Weight of Dry Brick, 6.92 lbs. per brick
Average Weight of Moisture, 1.215 lbs. per brick

These tests were enough for all practical purposes, and were found so valuable that they were made a permanent institution. The man in charge of the dryer therefore runs a test every morning and reports to the office the temperatures in each tunnel. This requires about an hour of his time, but we are assured that every day the whole dryer is operating properly and is in balance. It also insures an inspection of every tunnel. He makes sure that the flues are not blocked and that the dampers are in place, and if the brick are checking or softening, the necessary changes are made in that tunnel. The fact that there has been no large dryer loss except under abnormal conditions, and

THERMOMETER TEST No. 2. 6-25-09.

Lower Dryer						Upper Dryer						Tunnel No.
Front			Back			Front			Back			
Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	
102	120	45	90	94	88	99	182	3	85	90	82	1
102	142	34	92	94	92	94	144	19	90	96	80	2
104	126	43	90	92	92	96	184	2	85	90	82	3
100	160	19	92	94	92	100	170	5	86	90	86	4
98	134	30	92	94	92	92	144	24	84	90	81	5
104	144	31	90	92	92	98	194	0	88	90	91	6
102	168	20	96	98	98	96	172	8	88	92	85	7
110	160	26	92	98	95	94	150	21	86	92	79	8
106	158	25	96	100	86	92	146	19	86	93	75	9
100	158	20	96	98	93	92	142	23	92	96	86	10
106	164	20	94	100	80	96	152	18	86	94	74	11
106	174	12	92	94	92	110	200	1	86	96	68	12
108	182	10	100	104	86	102	180	8	88	94	78	13
104	132	45	92	94	92	98	160	17	84	90	81	14
104	156	22	96	102	80	....	.....	.....	....	.....	....	15
98	144	24	86	90	86	....	.....	.....	....	.....	....	16
98	140	23	90	98	73	....	.....	.....	....	.....	....	17
102	134	45	90	94	88	....	.....	.....	....	.....	....	18
Average	149.7	27.3	....	95.1	88.7	....	178.4	12.7	....	99.5	80.6	....

TEMPERATURES (Mean of Mean), HUMIDITIES WESTERN WASHINGTON.

		Winter	T. M. M.	Spring	T. M. M.	Summer	T. M. M.	Fall	T. M. M.	Annual T.	
Rel. H In %	8 A M	87	42°	85	50°	85	63°	89	52°	86	52°
	8 P M	79		60		53		72		66	
Grains Abs.	8 A M	2.47		2.84		4.02		3.40		3.18	
	8 P M	2.56				4.17		3.53		3.27	

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that the dryer has turned out its full capacity, has justified this expenditure. The dryer has been the limiting factor in our output which made this last point essential.

The writer lays the variation in temperature in differ-

THERMOMETER TEST No. 3. 6-26-09.

Lower Dryer						Upper Dryer						Tunnel No.
Front			Back			Front			Back			
Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	
96	122	44	96	98	93	98	152	21	88	104	54	1
102	142	33	94	96	92	102	184	6	88	96	73	2
98	138	29	86	90	86	104	158	22	88	98	68	3
96	124	34	86	90	86	102	170	15	87	98	65	4
96	124	34	88	94	78	102	172	14	88	96	73	5
98	134	34	90	94	82	100	160	18	88	94	78	6
97	130	35	88	96	73	98	160	17	88	94	78	7
106	162	20	88	94	80	100	168	14	90	94	82	8
104	140	35	86	90	86	102	160	20	88	96	73	9
108	163	21	94	96	92	98	154	19	86	90	86	10
102	160	20	94	98	86	104	180	10	94	102	73	11
107	168	18	94	96	92	104	182	9	93	106	63	12
102	154	22	87	90	88	106	202	0	92	98	80	13
102	144	28	94	96	92	105	188	6	92	98	80	14
100	140	27	86	88	92	.....	.....	....	....	.....	....	15
100	150	25	84	86	93	.....	.....	....	....	.....	....	16
98	132	37	84	88	85	.....	.....	....	....	.....	....	17
98	137	31	82	86	84	.....	.....	....	....	.....	....	18
Average	142.5	29.27	....	92.5	86.7	.....	170.6	13.6	....	97.4	73.3	....

ent tunnels partly to the difference in tightness of the various doors, and partly to the dryness or wetness of the car of brick in close proximity to the hygrometer. It is very important that the dryer doors be kept in good condition and arranged to close tightly. In making anemometer tests at another plant the writer has obtained readings as high as 2,250 C. F. M. in a tunnel in the opening leading to the exhaust duct when he could get no motion at all above, below or on either side of the cars of brick. On investigating it was found that the air was all passing through a crack under the tunnel doors. These cracks were covered with strips of belting, and the improvement in the drying was immediately discernable.

It has been noticed that the temperature on Monday

THERMOMETER TEST No. 4. 8-25-09.

Lower Dryer						Upper Dryer						
Front			Back			Front			Back			
Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	Wet	Dry	H%	Tunnel No.
100	170		86	100	57	106	190		88	92	85	1
106	225		90	110	46	106	210		88	96	73	2
101	190		88	102	57	104	184		86	90	85	3
104	206		90	112	42	104	190		88	104	53	4
106	200		92	108	54	104	180		88	101	60	5
106	216		96	112	56	104	190		86	98	61	6
109	220		94	123	34	106	192		88	96	73	7
110	240		92	134	21	104	194		87	98	64	8
111	224		94	108	59	108	190		89	98	70	9
106	190		90	102	63	106	192		80	86	77	10
112	198		94	110	55	106	214		88	92	85	11
112	192		88	102	57	112	214		86	91	82	12
102	180		94	120	38	108	200		88	94	79	13
110	192		94	110	55	106	182		88	93	82	14
110	204		86	104	48	108	212		87	92	82	15
112	190		96	112	56	112	196		86	91	82	16
108	196		....	.....	....	110	210		86	90	85	17
110	190		90	100	68	112	190		84	88	85	18
Average	201		91	110	48		196		87	94	75	

AVERAGES ON DATA FOR 8—24, 25 and 26, 1909.

	Bottom		Top		Average
Front Temp.	148.5		172.6		160.6
Back Temp.	93.6		99.3		96.4
Difference	54.9		73.3		64.
Front Hum.	26.9		12.5		19.7
Back Hum.	88.		76.9		82.4
Diff. Hum.	61.1		64.3		62.7

is naturally higher in the tunnels in proportion to the temperature in the blower duct, than on any other day of the week. This is, of course, due to the extra day's drying over Sunday. It is necessary, therefore, to watch the brick very closely to prevent checking the first of the week. To

offset this the usual procedure has been to cut the temperature in the duct down to 230 or 240 degrees Monday morning, raising it during the week until Saturday, when the temperature will be allowed to run up to 250 or 260 degrees. This policy protects the green brick made Monday morning and shoved in behind comparatively dry brick, which have had the benefit of the extra day.

Softening or slumping takes place at the exhaust end of the tunnels when there is too much moisture in the air. This does not occur except when there is water in the duct from the kilns or in the blower duct. When there is, it is necessary to drop the temperature in the ducts below the boiling point, 180 to 200, which gives 140 to 170 degrees at the hot end of the tunnels, otherwise so much water is taken up by the air passing over this water that when the cool end of the tunnels is reached the condensation softens and squashes the brick. Water in the waste heat duct is a much commoner occurrence than it should be, throughout the country, and is responsible for a good many troubles that are very often laid to something else.

Waste Heat from Kilns.

Four methods are used in removing the waste gases from the kilns. On the 150 foot rectangulars the heat is taken out of the crowns as previously described through openings, each containing six square feet, and then drawn through three by four foot overhead ducts. These ducts are supported on the kiln walls and between kilns upon trusses formed of sixty pound rails. The walls of these ducts are made of fire brick and are four and one-half inches thick, stiffened by pilasters. The top covering is made of fire brick laid flatwise between T irons and covered with cement. Built this way the ducts show very little tendency to crack except the portion resting on the crowns. An expansion joint allows to some extent for the rise and fall of the crown, but the mud bucket is in demand every few burns.

On the smaller rectangular kilns the heat is drawn from the kiln flue at the stack in the conventional manner. This is supplemented, however, by an opening cut in the upper part of the kiln and in the stack, which is built against one end of the kiln. By dampering the top of the stack it is possible to draw heat from the top of the kiln as well as from the bottom, the stack forming a sort of downtake.

On the round kilns the heat is drawn downward through the bags. This is accomplished by running a small subsidiary duct from the waste heat duct up under the ash pit, covering the opening with a plate which is removed by means of a device similar to a stove-lid lifter mounted on wheels. As soon as the fires are out the ashes are raked from two or three grates, the lid is removed and set up cross wise over the ash pit opening, and the gases begin immediately to pass downward through the firebag into the waste heat duct.

It is difficult to say which is the most efficient device, as each one seems to suit its own conditions best. In the writer's opinion it makes little difference as far as the dryer is concerned from which part of the kiln the heat is removed. It has got to come down any way, and if sufficient opening is allowed per thousand brick either method seems to prove efficient. The effect on the cooling brick is another story.

DISCUSSION.

Mr. Richardson: I want to say that I am very much indebted to Mr. Farnham for this valuable paper. I am glad that we are to have it on our records, as I do not know where there is another paper giving the principles and calculations involved in drying and in the construction of a dryer, and also actual data from practical drying operations; and we who are engineers are especially glad to know that we have such a paper in our Transactions for reference. Of course, it would be impossible to discuss

Mr. Farnham's calculations here, but the general scope of the paper and the method of handling I want to commend. With regard to the advantages and disadvantages of the double dryer: Of course, we understand that this dryer was built because they did not have room to extend it on the ground, and the only way was to put one dryer on top of the other. Now, I would like to ask Mr. Farnham, if he had room on the ground, would he consider the building of a double-deck dryer?

Mr. Farnham: I rather think I would, unless the kilns were very much spread out along the front of the plant. Did you ever watch the dryer either on a clear day and see the heat rising above the dryer and radiating into the air, or watch it on a rainy day and see the great amount of water that is converted into steam and rises from the dryer? You will then realize that the saving of that radiation is an important matter. Of course, much would depend upon the general yard lay-out you had, but I see a good big saving in radiation, and the fact that you don't have to carry your brick out a great distance and bring them back again.

THE REQUIREMENTS OF POTTERY MATERIALS.

BY

HARRISON EVERETT ASHLEY,* Pittsburg, Pa.

BODY MATERIALS.

White earthenware bodies are usually composed of "flint" (silica, as quartz or as true flint), china clay (kaolin), ball clay, feldspar, and stain. Occasionally Cornwall stone is introduced. While the addition of fluxes, such as whiting, in small amounts is feasible for lowering the temperature of the biscuit burn, it is not known that this is ever done here.

Flint.

True flint (an amorphous form of silica), calcined and wet ground, is extensively used in England, from which country our potting industry was transplanted.

In this country, ground quartz sand (Illinois) or sandrock (Pennsylvania) are commonly used, and incorrectly bear the name of "flint."

The crushed sand-rock is liable to be contaminated by fine iron particles from the crushing machinery. This may be readily detected by drawing a magnet several times through the sand. Sand so dirtied is to be rejected unreservedly, whether for grinding to "flint" or for placing ware in saggers; as it will cause a high percentage of "thirds" ware from unsightly brown specks. Iron may also be introduced from the floors of dirty cars, from the wear of soft steel shovels used in repeated rehandlings of the material, from engine cinders, from rusty car roofs, etc. Only the hardest steel shovels should

* By permission of the Director of the United States Geological Survey.

be used in handling pottery materials, in order to reduce wear to a minimum. Only tight closed cars should be used in shipping pottery materials. The best are those in which the previous loading was grain. Closed cars are also the easiest to unload, as a wheelbarrow may be run in close to the material, filled, and run out on a plank to the place of storage or use.

In English practice, the flint is fine ground wet in drag mills. Periodically the mill is stopped, allowed a short time to settle, and then the suspended ground material run out into a settling ark. From the latter, the thickened slip is carried in tank wagons to the place of use.

In American practice, the quartz sand is put into a four or five foot diameter ball mill, lined with wooden or flint blocks, and partly filled with imported flint pebbles as grinding material. It is ground from four to eight hours, depending on the lining of the mill and the requirements of the customer. If ground equal lengths of time, the product of the flint lined mill is much the finer.[1] Fragments of wood are found in case the mill is wood lined. There is much dispute as to the relative merits of English wet ground flint and American dry ground quartz. The writer has found such samples as he has tested to be much alike in fineness. The tendency of the American quartz to cake on the bottom when allowed to settle is probably a peculiarity of the mineral, not of the process of grinding.

Uniformity of grinding is very essential since, other things being equal, a change to finer ground quartz tends toward cracking of the ware and increased biscuit loss; while a change to coarser quartz tends toward crazing, reduced biscuit loss, and straighter ware. The crazing is easily avoided by a slight reduction of ball clay or feldspar, or by an additional amount of quartz and harder burning of the bisque.

The quartz is the skeleton of a white earthenware body, and its function is much the same as that of grog in

[1] Trans. Am. Cer. Soc., Vol. X, pp. 133-144.

a sagger. In the latter case, the coarser grog gives the more enduring sagger. This is likewise true of quartz in a body. Six hour quartz from flint lined mills leaves less than 0.5 per cent. residue on a No. 13xx silk lawn when sifted with the aid of a stream of running water. The writer decidedly prefers quartz leaving between 2 and 3 per cent. residue on No. 13xx silk lawn, as giving much less bisque loss.

To test the color of flint or quartz, it was put through a bisque kiln fire in the hottest part of the forebung. After noting the degree of sintering, a little was scraped to a powder, and put in a pile on a sheet of blue paper. Similar piles of samples kept as standards were placed beside it, and each pile moistened with water. This brings out the colors very strongly. True flint shows a very pure white, while quartz shows a pale buff or stronger rose.

Some mills let considerable gudgeon grease get into their ground materials. This is detected in wet sifting as oily pellets that are retained on the lawn. The pellets are broken up in blunging, so that the finely ground metallic iron contained in them is one of the factors toward a body of inferior color. With proper design and care this fault can be wholly avoided.

Spar.

Feldspar, as used by potters for bodies, is approximately a pure orthoclase (potash feldspar), but usually several per cent. of soda replaces a portion of the potash. A high soda feldspar would be objected to on the ground that ware made with it sounds dull. Experiments by A. S. Watts[2] show that such ware may have as much strength as that of a brighter sound.

Mixtures of soda feldspar and potash feldspar have a lower melting point than that of pure potash feldspar. Such mixtures, either natural or artificial, are more in favor for glazes than for bodies.

[2] Trans. Am. Cer. Soc., Vol. XI, pp. 179-184. (1909).

Day and Allen[3] have found that chemically pure orthoclase ($K_2O \cdot Al_2O_3 \cdot 6\,SiO_2$) has a much higher melting point than the commercial article. Vogt[4] and others have shown that additions of quartz to orthoclase decrease the melting point but little until a minimum is reached with 25 per cent. quartz.

The writer is informed by Mr. John M. Manor, who has had many analyses made of feldspars, that it is impossible to tell by inspection of the mined rock which of several feldspars has the higher content of silica. A Maine feldspar showing much free quartz analyzed lower for silica than another feldspar with apparently no admixed mineral. Both had high potash content.

The feldspar is the constituent that cements the body together at high temperatures. It is a matter of great importance at what temperature that action begins and how rapidly it proceeds; for claywares are most successfully burned when the vitrification is a gradual process, extending over a considerable temperature range. If the feldspars are compared[5] only in the bisque kiln at, say, cone 8, two samples may appear equally bright; yet the same feldspars may show very considerable difference at cone 6 or 4. Most feldspars, at cone 8, show a reddish gray shade, which is not usually considered an objection if the fusibility is satisfactory. Several dark burning minerals—hornblende, tourmaline, and black mica—if not completely separated, show in the fired sample or finished ware as very fine black specks. These would hardly be noticed by the uninitiated, but contribute a gray cast to the ware. Commercial feldspar is usually less contaminated with metallic iron than is quartz.

The writer believes that feldspar, of all pottery materials, is the one that it is most desirable to obtain a

[3] Am. J. Sci., 4th series, 19, 127, (1905).

[4] Edward Berdel: Sprechsaal 37, Nos. 2-11, (1909).
Zoellner: Sprechsaal 41, 471, 490, 504, 519, 533. (1908).
J. H. L. Vogt: Min. Pet. Mitt., 25, 361-427.

[5] Trans. Am. Cer. Soc., Vol. IX, p. 58, (1907).

chemical analysis of. Suppose, for instance, we have a soft (low melting) potash feldspar, we do not know whether its softness is due to (1) mechanically admixed soda feldspar, (2) soda feldspar crystallized with the potash feldspar, and thus far more intimately associated than in the first case, (3) mechanically admixed quartz, or (4) potash feldspar crystallizing with an unusually high amount of silica. The last case seems improbable, yet the writer has been shown evidence of its existence.

Suppose that four feldspars, one from each of the preceding four groups, show the same melting point, it is most probable that their action in a body mix will be very different. The writer would expect cases 1 and 2 to give much more vigorous fluxes than cases 3 and 4. He would also expect 2 to surpass 1 and 4 to surpass 3. A thorough investigation of the action of feldspars under these different conditions upon the rate of vitrification of bodies is much to be desired.

The more finely ground a feldspar is, the more uniform will be its distribution through the body, and the larger will be the area upon which it first exerts its cementing action. If in coarse grains, it will have to flow to fill the various pores, and reach the grains of quartz and clay that it is to cement together; but if fine ground, it will merely have to soften in position. It follows then that the fine ground feldspar requires less time to mature a body; that the body thus does not approach so near to fusion, its particles are less disturbed, and the tendency to bending and warping is much reduced. Flint-lined ball mills can readily turn out a product having less than 0.5 per cent. residue on a 13xx silk lawn.

Four or five per cent water, well mixed in at the mill, is required to lay the dust efficiently in a car of hot feldspar or quartz; but if the car is to be a week or more on the road, the wetting is not so necessary to the health and comfort of the laborers that will unload it.

Cornwall stone is a weathered granitic rock or por-

phyry that is much used in place of feldspar, especially in England. Its composition is variable, but, roughly, kaolin 11, quartz 22, feldspar 67. These are mechanically mixed, not in chemical combination. The writer has made comparative bodies, using in one case Cornwall stone, and in the other case amounts of kaolin, quartz and feldspar equivalent to the stone, and has failed to note any difference in shrinkage or water absorption.

The kaolin, quartz and feldspar are mixed in Cornwall stone in about the proportions for maximum fusibility of mixtures of these three ingredients. Thus a sample of Cornwall stone fired in a cup to cone 8 will appear as bright as some feldspars. It does not follow that if equally fusible it will be as good a flux. The writer believes that in those cases where the substitution of Cornwall stone for feldspar has proved beneficial, the feldspar content of body or glaze, as the case might be, was too high. The substitution of Cornwall stone for feldspar is equivalent to cutting out one-third of the feldspar and replacing it by one-ninth kaolin and two-ninths quartz. As the commercial Cornwall stone is more variable in composition than any other potter's material, it is suggested to those wishing to use it that they mix china clay, quartz, and feldspar in the proportions given above, and avoid the irregularities and extra cost of importing English "stone."

Ball Clay.

Ball clay is the most important and ordinarily the least controllable ingredient of a body. Its function is to supply the colloidal or gluelike matter necessary for plasticity and for cementing the ware together in its raw state. In addition, the English ball clay commonly used contains a portion of feldspathic matter in sufficient amount to vitrify it at cone 8, showing a shining conchoidal fracture. An American ball clay, on the other hand, will commonly show on analysis nearly the theoretical composition of clay substance, and will be very porous when burned to

cone 8. Only a few American ball clays vitrify at cone 8. The feldspathic matter in ball clays, being in a finer state of subdivision naturally than that obtained by grinding, is in an especially desirable condition.

The writer[6] has shown that English and American ball clays do not differ essentially in content of colloidal matter. The finer grained of two ball clays of equal colloid content seems the most efficient in cementing together an unfired body.

The writer has also shown that the colloid matter of ball clay has only about half the linear air shrinkage of that of china clay (kaolin). This is an experimental justification of the practice of potters to "get the color from the china clay and the plasticity from the ball clay;" for with its lesser shrinkage goes reduced losses in manufacture.

Of two ball clays showing equal toughness when the dry test piece is whittled, that is the more desirable that requires the lesser amount of water to make a slip that can be lawned.[7] Evidently if 400 per cent of water is required the shrinkage will be greater than for a clay that takes only 200 per cent. The writer does not like to see over 12 per cent. linear air shrinkage on a cast 10 cm. disk.

Preliminary to blunging it is customary to keep ball clay in a soak pit at least 24 hours, better a week. Repeated determinations of the percentage of water in several soaked ball clays have failed to show variation more than 1 per cent. above or below 30 per cent. of the total weight. The weighings are therefore made with an accuracy of 2 per cent.

The poor color of ball clay is tolerated because of its plastic and cementing properties. Color tests are described under China clay.

Ball clay, especially English, is apt to be intolerably

[6] Trans. Am. Cer. Soc., Vol. XI, p. 544, (1909).
U. S. Geol. Survey Bull. No. 388, p. 48, (1909)
[7] Trans. Am. Cer. Soc., Vol. IX, p. 54, (1907).

dirty. The writer has refused shipments that in transit had been dumped upon machine shop scrap, iron pyrites, and ochre. Cinders from docks or railroad yards are frequently thrown in when cleaning up before closing the car door. The English clay is liable to be transferred 6 to 12 times in transit; while, under favorable conditions, an American ball clay may go in a through car from the mine to the works.

Also the English clay very commonly has naturally occurring iron carrying lignite and pyrites. Some of the American ball clays are remarkably clean, and the average are decidedly cleaner than the English.

In making the whittled test,[8] only one side is cut smooth, while the original surface is carefully preserved on the other. After firing one can tell from inspection of the two surfaces whether the specks of dirt are natural or picked up in transit. The glost burn makes the specks more conspicuous.

China Clay (Kaolin).

China clay imparts to the surface of whiteware the characteristic soft mellow texture that distinguishes it from the hard glitter of glass. Apart from this, the function of fine grained china clay is mainly that of a filler, the quartz having supplied the skeleton, the ball clay the cement of the green body, and the feldspar the cement of the fired body. A coarse grained china clay (one of low surface factor), however, supplies a portion of skeleton more refractory than that of quartz; and bodies made with such clays are especially "safe" from warping at high fires. The North Carolina kaolins and a few English ones have this coarseness.

China clay is treated much better by transportation companies than ball clay. Its most serious impurity is a naturally occurring red-burning mica. A white-burning mica is unobjectionable, unless in excessive amounts. It

[8] Trans. Am. Cer. Soc., Vol. IX, p. 54. (1907).

may even impart some of the desirable qualities of North Carolina kaolin.

Dark burning sands occur in some otherwise desirable china clays. Frequently they might be removed by proper washing. Usually the American miner washes with much less skill than his European rival. Naturally, he finds the trade sceptical of his ability to supply a product of uniform high quality, but has himself mainly to blame for having failed to secure professional advice in the design of his plant, and trained men for the management of it. The writer is of the opinion that a great advance in efficient and economical methods of clay washing would result from a proper experimental study of its problems.

A rapid test for dirt in china clay, to be applied before unloading a car, is to put 100 cc. water in a glass cylinder, add about 5 grams clay, shake vigorously, and hold horizontally one minute. The heavy dirt grains will settle out on the walls of the tube, and be plainly visible. (It would take 10 minutes settling if held vertically, and the grain would not separate so readily).

The character of a crude or washed kaolin is best tested by running the sifted clay slip through the Schultz elutriating apparatus.[9] This the writer will shortly describe quite fully and critically in a bulletin of the U. S. Geological Survey. With the three-can form usually employed, a coarse, a medium, and a fine residue, and a very fine overflow are obtained. English clays as marketed usually leave very little residue in the first and second cans. One of the "safest" English clays leaves, however, a noticeable amount in the second can; while two clays that have given trouble from cracked ware leave only about 3 per cent. in the three cans, letting 97 per cent. go to the overflow. A very "safe" North Carolina clay leaves mica

[9] Handbuch der gesammten Thonwaarenindustrie von Bruno Kerl, (1907), page 78.
Wiley: Agricultural Analysis, Vol. I, p. 208, (1894).
Krehbiel: Trans. Am. Cer. Soc., Vol. VI, pp. 173-185, (1904).
Binns: Trans. Am. Cer. Soc., Vol. VIII, pp. 2444-251, (1906).
Parmelee: Trans. Am. Cer. Soc., Vol. XI, pp. 467-493, (1909).

in the first can, and a large residue of medium clay in the second can. Any metallic iron and most pyrites will be retained in the first can. A Georgia clay that burnt to a very bad speckled appearance showed yellow grains in all three cans. Another Georgia clay, sold for saggers because badly stained, left all its dirt in the first and second cans, and had clean clay in the third can and overflow. In testing a crude clay to find what percentage can be obtained by a washing plant of proper design, one may estimate the first and second can residues as sand and the third can residue and overflow as clay; although, as above stated, the second can residue, if clean kaolin, is very desirable. However, the trade in general thinks the finer the clay the better it is, and does not understand the value of coarse China clay.

As suggested under ball clay, a china clay of high shrinkage is very undesirable, and leads to high losses. The colloid matter necessary for plasticity is much better secured from ball clay; and fat china clays should be avoided. The writer does not like to see over 6 per cent. air shrinkage on a cast 10 cm. disk.

Colors may be compared[10] with a series and standards prepared by blending a very white china clay with a dark buff Tennessee ball clay in convenient proportions. The glaze used on the standards and all tests should be the same, as different glazes on the same clay give very different shades. Using such a color scale, the writer has found the English china clays used for whiteware to range from 75 to 100 per cent. of white clay in the color standards, though a given china clay is usually constant within five points on the scale. A certain Middle Atlantic States china clay has shown continuously a variation from 50 to 85, was clean at times, but ordinarily specked. A certain southern china clay has varied between extremes of 50 and 90, though ordinarily only from 60 to 75, and is always clean. A certain North Carolina kaolin has kept within

[10] Trans. Am. Cer. Soc., Vol. IX, p. 56, (1907).

limits of 78 and 90, but is not always equally clean. Any point of the scale may be matched among the clays of Georgia. On this scale, English ball clays range from 20 to 0 or darker. As they differ in tint from the china clays, comparisons are easier made with a set of gray standards. American ball clays range from 50 on the china clay scale used by the writer to clays as dark as any English clay.

Body Stain.

The natural creamy tint of claywares is overcome in whitewares by the addition of cobalt, which produces a much less noticeable blue green tint.

In the manufacture of white papers, the yellow tint is neutralized by blue dyes, also resulting in a green tint. The latter is then neutralized with a red dye, giving a gray shade, devoid of color. So far as is known, no similar attempt is made to neutralize the green tint of pottery wares by any addition of red coloring matter; nor has the subject been investigated.

Black oxide of cobalt is the form of cobalt most used. According to various authorities its formula may be Co_3O_4, Co_2O_3, or Co_3O_5. It is liable to contain nickel, copper, etc. As these are difficult to detect by tint alone, a chemical analysis should be made of each brand seriously considered for use. The coloring strength of different lots of cobalt oxide against a standard lot may be roughly compared by thoroughly mixing cobalt oxide with a standard feldspar in proportions from 1 to 1000 to 1 to 20000. Each mixture is put by itself in a bisque cup, pressed down firmly, covered, fired at cone 8, and broken from the cup. In this test, an inferior cobalt will sometimes show a "sad" color in comparison with the standard. A fluxed cobalt exposed itself by glazing the adjacent surface of the cup. There are many brands, but the same brand from different dealers does not always prove to be the same grade. The leading dealers, however, are reliable, and owe their leadership largely to honorable dealings. To avoid the necessity

of fritting and grinding, and the occurrence of blue specks, soluble cobalt salts are used to some extent to color bodies. In some factories, the cobalt salt is simply added to the blunger, and the clays are expected to absorb or take up the cobalt. Experiments and calculations by the writer, however, show that in such cases only about two-thirds of the cobalt is retained by the clay, and one-third goes into the filter press water. If the latter is thrown away, one-third of the cobalt is lost, but if the press water is reused there is no loss. The simple solution of the cobalt salt is unsuited for cast ware, as it effloresences on the edges in drying. It is then better to precipitate the cobalt in an insoluble form by the addition of ammonia or other alkali just before use.

The glaze is not stained ordinarily.

GLAZE MATERIALS.

Some glaze materials have been fully discussed under "Body Materials," and need little further mention.

Frits are not commonly purchased, and are best treated elsewhere.

The fineness of grinding of **Quartz** and **Feldspar** are of importance merely as regards the amount of further work that the glaze mill will have to do to them.

Ball clay is not used, as its color would darken the glaze.

China Clay.

China clay is perhaps the principal source of the colloid matter that sticks the unfired glaze powder to the biscuit body. The use of a more highly colloidal china clay for a less colloidal one will increase the adhesion; as, for example, the substitution of Florida kaolin for English china clay. The wet grinding of feldspar, quartz, and frit also produces considerable amounts of colloidal matter. Too fine grinding, too much clay, too fat a clay, or a combination of these will so increase the total colloids as to

cause by their shrinkage cracking of the glaze as it drys on the ware, or rolling up in the kiln at the beginning of firing.

Lead Compounds.

Old Dutch process white lead is commonly preferred, as it stays in suspension well in the glaze tub. The writer has found the Danish process precipitated white lead to be still finer and slower settling in the case of the makes examined, and that no trouble resulted from its use. The writer has not encountered adulterated white leads.

Red lead is a finely divided article, but seems more dense or crystalline than the white leads. It is used in sagger glaze, so that the pink tint imparted may prevent accidental use of it on ware, and will help the sagger washer to distinguish it from the "flint" wash.

Lime Compounds.

The levigated natural carbonate, "English cliffstone paris white" is preferred. This preference is based on its fineness and colloid content. The better it is, from this point of view, the better it snaps when a small dry lump is broken by the fingers. An elutriation with the Schultz apparatus will serve to determine the fineness.

A chemical analysis is well worth while when considering a new brand or hunting for the source of trouble. For good color, the iron should be low. Sulphates are inexcusable. Only a small per cent silica and alumina should be present. Magnesia should be under 1 per cent, as it ordinarily gives trouble in an American factory.

Lime is used to a small extent in glazes. Its function is not well understood, but is probably to precipitate both the boric acid and the colloid silica and silicates from solution. If this supposition is correct, the lime should not be allowed to become air slaked before use. The correctness of this supposition is supported by the fact that it is not necessary to use magnesium sulphate, acetic acid, or other

coagulants when lime is employed. Lime should be selected on the basis of chemical analysis like whiting.

Zinc Oxide.

Zinc oxide, though alone more refractory than lead oxide, acts as a flux in much the same manner when introduced in small quantities. It is supposed to be a whitening agent.

It is supplied in numerous grades: White Seal, Green Seal, Red Seal, (which three are usually imported), Potters' Selected, XX, etc. If put into a closed bisque cup, and fired in the glost kiln, the first two of those mentioned show a faint green; the Red Seal, a bright yellow; the Potters' Selected and XX a darker yellow. The poorer grades show brown spots. From these trials, one's first impression would be that all but White Seal and Green Seal are to be condemned for good ware. However, the writer has failed to find any inferiority in whiteware glazes made with Potters' Selected and XX grades. Bristol glazes, containing a high percentage of zinc oxide, also failed to show any color difference with these zincs and Green Seal. Zinc oxide is frequently offered for sale under the name of a better brand than corresponds to its true grade. Chemical analysis should assist the firing test above mentioned.

Boric Acid.

Boric acid in a pure refined crystalline condition is manufactured in this country. An impure crude brown flaky Tuscany acid is, notwithstanding, largely imported and used—this, though after paying a duty of 5 cents per pound, costs about 2 cents per pound more than the pure home article. The reason for this expensive practice is simply ignorance and caution. The first is regretable; the latter is of time proved value, for most attempts to substitute "white acid" for "brown acid" have led to crazing. The Pacific Coast Borax Co. have kindly made analyses

of two samples of brown Tuscany boric acid selected by the writer.

Analyses of Brown Tuscany Boric Acid.

BY

K. Jacobi, Bayonne, N. J.

Date	Sept. 15, 1905	Nov. 28, 1905
Boric Acid	80.76	82.46
Silica	.71	.87
Alumina and Ferric Oxide	.33	.28
Lime	.85	1.40
Sulphuric Anhydride	9.32	8.46
Alkalies	2.59	2.08
Ammonium Oxide	4.23	3.75
	98.79	99.30
Magnesia	trace	trace
Organic	A small amount	A small amount

Tin Oxide.

Tin oxide is occasionally put into a glaze. It does not dissolve, but stays in suspension, imparting a white opacity to the glaze. Its object is then to hide a poor body. As it is an expensive material, it should be analyzed, both to make sure of getting what is paid for, and to avoid undesirable impurities.

The ammonium oxide and lime are present mainly as sulphates of harmful nature; the alumina and silica as clay; and the alkalies combined with a part of the boric acid as borax.

The writer has calculated the proportions of unobjectionable material that should be substituted to give the same fluxing effect as this acid, but without the harmful sulphates:

Date	Sept. 15, 1905
White Boric Acid	70.76
Borax	15.44
Clay	.49
Feldspar	.73
Whiting	1.52
	88.94

It is seen that 88.94 pounds good material is equivalent to 100 pounds brown acid. Roughly expressed, brown acid consists of 10 per cent pure boric acid, 15 per cent borax, and 15 per cent of volatile matter and objectionable sulphates.

The writer tried the effect of making such a substitution in the glaze of the company by which he was employed. The frit was prepared in saggers according to the East Liverpool custom, but lay quiet and smooth. The same frit prepared with brown acid swells up to several times its true volume, even running over the tops of the saggers with especially bad lots of brown acid. Ware dipped in the white acid glaze was in no wise inferior to the brown acid glazed ware. The white acid glaze withstood the crazing test[11] perfectly, and was not dulled by it as the brown acid glaze is. Overglaze decorations, especially the greens, were much improved in appearance on this white acid glaze.

Materials of constant and pure composition can thus be successfully substituted for the ever varying impure brown acid. The purer materials cost about 25 per cent less than the impure which they substitute, and produce much better ware.

Borax.

Borax is the best means of introducing sodium oxide into the ordinary white ware glaze. It contains boric acid also, as shown by the formula $Na_2O \cdot 2\,B_2O_3 \cdot 10\,H_2O$. The commercial article is ordinarily satisfactory. It should not be stored in so hot a place as to alter in composition by loss of part of its crystal water.

Sagger Materials.

Sagger clays are exhaustively treated in a separate paper in this volume.

In beating out the bats for saggers it is necessary, to

[11] Trans. Am. Cer. Soc., Vol. IX, p. 59, (1907).

prevent sticking to the table or block, to strew the same with sawdust or sand. A round grained sand should not be used, as it is liable to drop off onto glazed ware in the kiln. The use of sharp sand is debatable. When a sagger made with coarse sawdust is first burned, the contents of the sagger below are strewn with the ash of the sawdust, which in some cases adheres. A cupful of any lot of sawdust should be burnt in the kiln before using to see whether its ash will make trouble. Only fine grained clean sawdust should be used.

Sagger wads have less and finer grog than saggers, and require very tenacious clays. The finest dust should be sifted from the grog used, and coarse quartz and pyrite should be rigidly excluded.

Placing Sand.

The round grained quartz sand of Illinois is best suited for placing ware. It acts like roller bearings, permitting an unrestricted shrinkage of the ware. The rolling fraction will be least, with the grains of all nearly the same size. The sand has most tendency to pack when 0.5 to 0.2 of the total is quite fine. It is recommended that everything retained on a 40 mesh sieve or passing 100 mesh be sifted out. The fine stuff so rejected might be used mixed with ground "flint" for lining frit saggers. Sand coarser than 40 mesh will make marks on ware, and may make so irregular a bearing as to cause cracks in the ware.

The fine sand requires great care in brushing off the bisque ware before dipping. A slight oversight in this respect will cause many pieces of glazed ware to show raised white specks in the glaze. If everything passing 100 mesh (or better 80 mesh) is screened out, the labor of brushing will be greatly reduced, and the quality of the ware improved.

A sample of each lot of sand should be put into a covered unfired cup, and fired in the bisque kiln. It should

not adhere firmly to the fired cup, nor discolor it. Car cinders cause unsightly specks. Crushed sands, as from the Pennsylvania and West Virginia sand rock, are liable to be filled badly with specks of iron worn from the crushing machinery, and should be tested with a magnet before unloading.

PINS AND STILTS.

Pins and stilts are made from tough clays that do not yield at kiln temperatures. They should have sharp points that break easier than the glaze to which they adhere. They are supplied with very few broken pieces, and should be without fins, and free from dirt.

BITSTONE.

Bitstone is a coarse sharp grained crushed quartz. It is filled into bisque saggers and calcined in the kilns once before use, in order to prevent it from flying about explosively in a glost sagger, and thus specking the glaze. It is essential that it be of uniform size, say through 6 mesh and on 8 mesh, in order that it may carry ware level and securely. It should be sharp so that the point fused into the glaze on the bottom of the piece of ware may be as inconspicuous as possible.

COLORS.

The colors used are required in such small amounts that it is usually best to buy from reliable dealers. So much depends on physical properties that chemical analyses are ordinarily of little use, and comparative tests must be made. The decalcomanie decorations are to be tested similarly. Decalcomanie size also must be tested under the conditions of use. It should not prevent the colors or gold from attaching firmly to the glaze. The size or colors should not contain any constituent, like wood alcohol, injurious to the health of the decorators.

PLASTER PARIS.

Plaster paris was fully discussed two years ago in the Transactions.[12]

ACKNOWLEDGEMENT.

I am much indebted to my friends and fellow workers whose advice, suggestions, and queries have done much to direct my ideas on these subjects. In particular, I would mention Messrs. Ernest Mayer, Joshua Poole, C. H. Walker, Charles I. Aaron, John Herbert, James Miles, Edward Orton, Jr., and A. V. Bleininger.

DISCUSSION.

Mr. Simcoe: I would like to ask Mr. Ashley what effect on the time of grinding of the flint and spar does the presence of clay have?

Mr. Ashley: I have no experience with that, but I think the nearer we can keep to wholly crystaline materials the more rapid the grinding will be, and that the clay will have a retarding influence. But I have had no experience on that.

Mr. Purdy: Concerning the discussion which Mr. Ashley gives about distinguishing by chemical analyses the mechanical mixture of soda and potash feldspar from the isomorphous mixtures of the two, I would like to ask him how it is done.

Mr. Ashley: I did not intend such a connection. I emphasized the value of chemical analysis and then went on to mention the causes which produce equally low melting points. Chemical analysis would distinguish those cases mentioned.

Mr. Cowan: A few years ago I was doing some experimental work on hotel china, and during the work I mixed up from the formula bodies in three different ways. In the first one I blunged, as is usually done in the ordinary

[12] Trans. Am. Cer. Soc., Vol. X, pp. 76-90, (1908).

pottery. In the second I took all the ground materials, and reground them in a ball mill for two hours and blunged with remainder of body. In the third case I took the whole body and ground it in a ball mill the same length of time, and under the same conditions, endeavoring to keep the same viscosity in both.

In using these two bodies in making up the trials they were both fired in the same sagger. On taking the trials out, there was a great deal of difference in them. The first trial, that in which all the materials were blunged in the ordinary way, gave the usual type of hotel china. In the second, it seemed to have received almost a cone higher fire, showing the influence of the fine grinding. That was the body in which the ground material had been reground. In the third body that had been all ground together there was almost a cone of difference in the translucency and in the color, etc.; showing that it is not so much the grinding of the materials that had the influence, but the intimate mixture that they received in the ball mill.

Mr. Ernest Mayer: I would like to ask Mr. Ashley if in that experiment with the coarse ground flint, there was any difference made in the temperature in which it was fired afterwards? He spoke of the coarse ground flint causing less loss and cracking less.

Mr. Ashley: No, sir, it was in the regular operation of the pottery, where I examined every car that came in. Some came in finer and some came in coarser. The biscuit loss of ware was also kept track of weekly. I kept records of the degree of coarseness of the quartz used, and of the biscuit loss, and found a sort of parallelism between the two. That is, the coarser the flint the less the loss was, the finer the flint the bigger the loss. At the time when they changed from wooden lined mills to flint lined mills at East Liverpool, they got a much finer ground product, and every pottery in town had trouble with cracked ware for some months, and then they gradually got adjusted to the finer flint.

Mr. Binns: That is parallel to the English experience when ball mills were first introduced. It was at one time thought that they could not use the ball mill, because on replacing the drag mill by the ball mill, it was found that cracked ware developed. The difficulty was solved, as suggested, by a coarser grinding. In other words, the grinding of the ball mill was so much more perfect than the grinding of the drag mill.

Mr. Purdy: Mr. Ashley spoke about the coarsely ground feldspar causing either more or less rapid vitrification; I did not catch which.

Mr. Ashley: Less rapid.

Mr. Purdy: And then he immediately said the potters should grind their feldspar finer. I do not recall that he gave any reason for this. I infer, however, that he believes they want rapid vitrification.

Mr. Ashley: I stated that with the finer grinding it would be more uniformly distributed throughout the body, and you consequently would have to do less flowing in cementing the material together, and so would have less tendency to produce distortion of the ware.

Mr. Purdy: That is the point I was leading up to. Have we much distortion of the ware due to orthoclase feldspar? Does the fact that a piece of feldspar that is 100 per cent pure can be completely fused when lain across the top of a crucible without showing the least sign of deformation or deflection from a straight line, indicate that much warpage or deformation in the ware is due to feldspar? I contend that distortion of ware is due to viscosity of the molten or fused portion of the mixture of clay, flint and feldspar being less than that of feldspar alone. I agree with Mr. Ashley in the statement that finer grinding of the feldspar will result in more rapid vitrification. I know, however, that there would be greater likelihood of distorted ware. I do not believe that coarse grinding of this feldspar will cause distorted ware. It would make less smooth surface and rougher looking body.

Mr. Ashley: The American potter has never used such material. If a sample of it were presented to him he would say it was too hard and cast it aside.

Mr. Purdy: That is dodging the issue. Most of our feldspars are nearly pure orthoclase, that is, if Mr. Ashley's statement is correct. Our potash feldspars are diluted to some extent by soda and also by the lime-soda feldspar. It happens that the soda feldspar is much more liquid when fused than is the potash feldspar. It is only in rare cases, however, that we have the soda feldspar. The soda feldspar that we do have is not anywhere near pure. It is largely admixed with potash feldspar. Taking Mr. Ashley's own testimony for the feldspars generally used, being potash feldspars, are we not to say that he is contradicting himself?

Mr. Ashley: To give a numerical expression to what I said, I would say that the potash feldspar to which I referred would have perhaps 15 per cent of potash and 3 per cent of soda, possibly only two per cent of soda, possibly five per cent of soda.

Mr. Purdy: There is one other point with Professor Binns. A little earlier he described the value of a rational analysis of a clay in deciding what clay is to be used for a given purpose. Now we have testimony that commercial china clays that apparently are pure, or at least have been supposed to be pure clay, have, in extreme cases, 30 per cent of mica. Would his rational analysis show that?

Mr. Binns: I do not think I can answer that question offhand, except in a guarded way. It has been shown by German investigators, and if I remember rightly Mr. Stull in an earlier paper discussed the question, that mica behaves in a very similar manner to feldspar. And if that be so, we are not very far out in calculating the alkalies as the bases of feldspar, even though a part may belong to mica.

Mr. Purdy: Mr. President, I wish to introduce a topic for discussion more than to discuss it myself, and

that is concerning the different boric acids. In Zanesville a change was made from Tuscany acid to the crystalized acid, and they had trouble, not from crazing, but from various sorts of imperfections, blistering, scumming or curdling, and in some cases they had the positive appearance of dirt. Now I have been informed that in the whiteware they have found that their ware would be covered with pieces that resembled very much specks of grog or clay. These specks are scattered over the upper surface of the flat ware. The only source of the trouble so far as they have been able to determine is in the boric acid. What I want to introduce here is a discussion of these defects brought about through the boric acid.

Mr. Binns: I would like to ask in that connection whether Professor Purdy had any tests put through as to the complete solubility of the acid? If, as he suggests, there were any impurities in the acid, would not they readily have been detected by a solution in water?

Mr. Purdy: I have not any positive recollection of any such tests being made. So far as showing the presence of coarse ingredients or foreign substances, there was no object. If such insoluble material was present it would certainly have been observed when the acid was dissolved prior to making the sulphur determination. There was none observed. None was looked for, for that matter, but so far as I recall everything went into solution.

Mr. Campbell: I would like to ask what is the difference in manufacture between the White Seal, the Red Seal, and the Green Seal?

Mr. Ashley: I am not well enough acquainted with the process to know what it is.

Mr. Binns: Is it not simply a matter of time taken to sublime the zinc?

Mr. Stover: Do I understand that your department is working with a view to putting into the transactions in another paper the various standards of purity? You say that in buying materials you ought to know what you buy.

Do I understand that your department is working along the line of these standards?

Mr. Ashley: Our department has not been able to expand itself to any such extent. We are confining ourselves to a few principal subjects and putting all our energies upon them; but this paper is merely my own pottery experience. It dates back to the time before I was connected with the Survey.

Mr. Storer: I think that should be talked over with our senators and congressmen. If we tell them that our industry today depends on receiving materials of which we have no standards of comparison, I think they would see the necessity of making this department of investigation permanent.

Mr. Purdy: We have been told this afternoon that by a finer grinding of material whether it be flint, feldspar, clay, whiting, or what not, colloids are produced and increased in quantity. I would like to know what colloids we get by grinding.

Mr. Ashley: I hope to enlighten Mr. Purdy further on that subject with my paper tomorrow.

Mr. Ernest Mayer: I was very much interested in Mr. Ashley's statement as to oxide of zinc used in glaze. I would like to ask Mr. Ashley if his experiment was made with the same glaze by altering nothing in the formula except the oxide of zinc and then to see the effect on the color of the glaze.

I have had very little experience with the use of oxide of zinc in glaze except a few experimental trials, and in those trials I simply used a certain glaze and added various percentages, from 1% to 5% and possibly more, but I never found a particle of difference in the appearance of the glaze as to its color.

I have many times asked potters why oxide of zinc was used in a glaze and I never got a really good answer. I was prompted to ask this question because zinc is used practically by all potters in the United States making

white ware, and while I have seen hundreds of formulas for glazes of English, German and French origin, I do not recall ever having seen oxide of zinc in them.

My objection to the use of oxide of zinc in a glaze is its effect on underglaze colors, which is detrimental, in my opinion, particularly in reference to green changing many of the colors in a brown, though its effect on blue was beneficial.

Mr. Ashley: I have taken our glaze, filled a cupful and fired it, which gave a fairly clear glass. I have taken 98 per cent of the same glaze and two per cent of zinc oxide and fired them together and the glass became rather turbid or milky in appearance, so that with the larger amount of zinc it was beginnig to be somewhat opaque, but the amount we used regularly in the glaze had apparently only a fluxing effect.

Mr. Ernest Mayer: I asked the question because in the experiments I made I could not see any difference whether the zinc was in or was not in, as far as the glaze was concerned, but its presence had a marked effect on underglaze colors.

Mr. Binns: I incline to the belief that when the American potters began to use zinc oxide it was for the same reason that tin is used today, that is, to conceal a dirty ware, the idea being that zinc is analogous to tin, and the zinc would act in a similar way as tin oxide without being quite so expensive. In reality the small amount of zinc that is employed does not make the glaze milky or opaque, at the same time if zinc be substituted for lead, equivalent for equivalent, it does make the glaze whiter, not necessarily on account of any whitening influence, but because it removes the yellowing influence of lead. A glaze containing only lead oxide and lime will be distinctly yellow. If you substitute 15-100 equivalent of that lead by zinc you will whiten the glaze quite materially, because you will remove part of the yellowing influence that the lead oxide has.

Mr. Staley: About zinc whitening glass, I would like to say that I have used it in frits up to six per cent and have found no milkiness due to the oxide of zinc. In fact, I have used it as high as ten per cent in experimental batches, and found no milkiness.

The amount of zinc oxide necessary to produce opacity depends upon the composition of the glaze, in general becoming less as the Al_2O_3 and alkaline earth bases are increased.

In regard to Mr. Mayer's statement that zinc would be more expensive than lead, I believe "potter's selected" zinc oxide could be bought at the time I used it for six cents, and red lead costs seven and a quarter. When used in small amounts, that is, not over three per cent, zinc is as active a flux as the red lead pound for pound. When you load up your glaze with zinc so that the zinc refuses to go into solution, it acts as a refractory, raising the fusing point, and makes it white. We have that effect in bristol glazes.

One thing I would like to ask Mr. Ashley is where he buys feldspar with 15 per cent of potash and three per cent of soda?

Mr. Ashley: I cannot remember the exact composition of the feldspar at the present time, but that was my impression, but I may have been decidedly off as to the percentage.

Mr. Weelans: Pure orthoclase feldspar figures 16½ per cent potash.

Mr. Staley: As to the manufacture of zinc in the different grades, I have forgotten just how they are graded myself, but the difference between the commercial oxides of zinc is just one of fineness. They volatilize it in a flame and the part that goes to the farthest collecting chamber is the finest and brings the best price. The part that drops close to the furnace is the coarsest and brings the lowest price. The color increases with the coarseness. I do not know why it does. I have used all the grades of oxide of

zinc, from the ordinary grades up to the finest grade imported, and can see no difference in the colors produced from the different grades.

Another point,—Mr. Ashley says oxide of tin should be analyzed. There are several reputable manufacturers of oxide of tin in this country. Nearly every plant that uses oxide of tin in large quantities has had analyses made at different times and paid a good deal of money for it, and to the best of my knowledge there has never been any impurity found in the oxide of tin. They have spent their money for nothing.

Mr. Purinton: I would like to ask Mr. Purdy with reference to the trouble at Zanesville with the acid. I wish he would describe the appearance of the trouble in Zanesville ware from using the brown acid.

Mr. Purdy: It was not the same trouble that has been reported from East Liverpool districts. In Zanesville they were using colored glazes and the underglaze color. In these glazes, they had scumming with what Mr. Ashley tells us is the purest and hence the best to use, but had no scumming when using the brown acid. It looked as though there was lots of sulphur present, though sulphur could not be deteced in the pure manufactured boracic acid.

Mr. Purinton: The reason I asked is that the Liverpool potteries have been having a great deal of trouble during the last six months with their glaze ware. It has the appearance of sand on the flat surfaces of the ware, and yet with all the care and precautions it is not sand so far as we can ascertain and it is not kiln dirt. It appears to be a kind of a bubble that swells up and breaks and remains, not all over the finished ware, but only on the flat portion, not on the bottom part hanging downward in the kiln, not on the sloping portion of the ware, but on the flat portions facing up. Those having that trouble have been using Pacific boric acid. I have learned that one or two plants have returned to brown acid and eliminated the trouble.

Mr. Purdy: That was the Zanesville experience, yet we are told today that the brown acid contains from 15 to 20 per cent of impurities. What is the impurity?

Mr. Langenbeck: I found a large percentage of sulphate of ammonia in a brown Tuscan acid used in fritted glazes that scummed and crystallized on the edges of tile. Suspecting the sulphates introduced into the fritt by the acid, pure white acid was used, when the trouble disappeared.

Mr. Weelans: In corroboration of Mr. Ashley's statement with reference to the impurities of tin and the necessity of analyzing same, I might relate an experience a neighbor of ours had in connection with the use of tin in his glaze. His experience was that at various times he noticed these impurities in the tin which resulted in the ware being more or less spotted. After thorough experimentation with the various materials he discovered conclusively that these small yellow or red spots which occurred on the surface of the ware were due entirely to fine particles of iron in the tin. He took the matter up with the parties furnishing same, with the result that later they agreed to give a written guarantee for all future shipments of tin. No trouble was experienced for some length of time, but finally they had much trouble and loss. The matter was taken up with the parties furnishing the material, and after going into it carefully and proving conclusively the cause of the fault, they paid the amount of loss which was figured at $500.00. I might add that I have also experienced at various times like conditions, only less severe.

Mr. Shaw: I wish to say that my experience not more than two weeks ago was exactly similar to that just mentioned. We have been using tin for a good while from a well-known firm in this country, and about two weeks ago we received a thousand pounds, and trouble immediately developed from its use. I washed a sample of the tin and after finishing the washing there was about five per

cent of the sample left, and it was black. I immediately sent to another firm for a sample of tin and washed it, and there was absolutely no impurity at all. I do not know that these impurities, those black specks are iron. It is possible, at least it seems to me possible, that these black specks could be due to the insufficient oxidation of the tin, stannous oxide.

In regard to the zinc oxide, I performed experiments this winter to determine the effect of the different opacifying oxides, zinc, antimony and tin. I took a formula I was using to make enamels for sheet steel and added varying amounts of zinc oxide, antimony oxide and tin oxide. The additions were made in fractional equivalents but run as high as ten per cent in all cases. I found ten per cent of zinc went into solution easily, producing a very liquid glaze. Five per cent of antimony goes into solution. Ten per cent makes a glaze too viscous to pour out of the crucible. Five per cent of tin oxide goes into solution, making a transparent glaze. Ten per cent makes a practically opaque white glaze. Professor Binns has stated that if you replace lead with zinc you will get rid of the yellow color, because you can reduce the lead. In performing these experiments I got yellowish brown color. I did not use lead, but my brown color came from the iron of the crucible, I think. I found that the brown color was in the glaze that had the antimony and the tin in it, but there was no brown color in the zinc glaze. I took another sample of that glaze and added antimony, the same as I had before, and added the same amount of zinc. That glaze came out pure and clear without any color. I believe the function of the zinc oxide is more to destroy any tendency to yellow or dark colors than for opacity. In fact, I do not believe there is any value, so far as opacity is concerned, obtained from zinc, providing it is burned and receives a high heat treatment, as is used in burning and fritting enamels. It may be that in burning pottery glazes the heat treatment is not sufficient to take it into solution, but

I am positive that ten per cent of zinc oxide in some enamels will go into solution and five per cent of tin oxide. The amounts that will go into solution depends on the composition of the glaze used and the severity of the heat treatment.

Mr. Ashley:[13] In connection with Mr. Purinton's remark as to trouble with the glaze in East Liverpool for the six months preceding the Society's meeting, it is of interest to note that during the whole of the period the Ohio River (the soure of East Liverpool's water supply) was very low. It was common talk that it was very acid from the sulphuric acid waste of the steel mills and mine waters of the Pittsburg district. At one time during the period, large quantities of dead fish were floating on its surface, and an investigation by the U. S. fish commissioners, I think, (though it may have been a state health board) found their death due to excessive acidity of the water. It seems very possible that this extra acid was the cause of the trouble. If so, the trouble should cease with a return to a high stage of the river.

[13] Note by Mr. Ashley subsequent to the meeting.

TESTING SHEET STEEL ENAMELS.

BY

J. B. SHAW, Grand Rapids, Mich.

The subject of this investigation is one which may not be of special interest to more than a few persons present, and yet it is one which is of more or less interest to every person, dealing as it does with a class of ware that forms an essential part of the equipment of every kitchen, viz., cooking utensils. Not only has enameled sheet steel become quite generally adopted for use as household utensils, but it is very largely used for street and advertising signs, automobile tags, refrigerator linings, surgical ware, chemical and photographic utensils; and its field of usefulness is rapidly becoming broader, every step in the advance of the industry adding to its importance to the general public.

Volume XI of the Transactions American Ceramic Society contains an article by Prof. Orton, in which he describes tests made on this class of ware, and in which he suggests that the subject of testing enameled iron ware should be more thoroughly investigated. These remarks, together with a personal suggestion from Prof. Orton, prompted this investigation.

GENERAL CONSIDERATION.

There are three general agencies which tend to destroy the usefulness of enameled steel ware, viz: chemical action, sudden change of temperature and impact. The ideal piece of enamel ware is one that will stand the action of strong chemicals, especially acids, without harm, that will stand sudden changes of temperature from very high to very low or vice versa, without harm, and one that will

stand a great many severe blows without harm. Of course there are other properties of minor importance that can not be overlooked, such as color, gloss, and general excellence of finish, but the three properties named above are the fundamental properties of porcelain enamels, and every piece of ware must possess at least some one of these properties to a high degree, if it is to be of value.

As. Prof. Orton has shown, it is not necessary that all classes of ware possess all of these properties in the same degree, and just which of them is most important in any given case depends entirely upon the conditions to which the ware will be subjected. The tests to which any class of ware is to be subjected should be determined by the conditions which that class of ware is supposed to meet. Ware of the utensil class must necessarily possess all three of these properties to a high degree, but the chemical property is most important. Wares of the display class must possess the property of resisting impact to a high degree, the other two properties being of decidedly minor importance. From these general considerations it seems evident that in order to be able to cover the entire field of enameled sheet steel ware, it will be necessary to formulate methods for making three different kinds of tests, viz:

Chemical Tests,
Sudden Change of Temperature,
Impact Test.

PROPERTIES OF ENAMELS.

Chemical.

The ability of enamels to resist chemical action depends primarily upon the ultimate chemical composition of the surface exposed to chemical agents, but of no less importance is the degree to which this chemical union approaches a homogeneous chemical compound. The higher the percentage of unfritted materials added to the enamel the greater the danger of destruction by chemical

action. The covering power of the enamel might be mentioned as having some bearing here, but its influence is very slight as compared with the two foregoing properties.

Adhesion.

The sudden change in the temperature of a piece of enamel ware introduces conditions which are especially adapted to show the fitness of the ware for its purpose.

Assume a piece of this ware heated to 400 degrees C and dashed into water at 15 degrees C. What are the conditions introduced? The exterior surface or cover enamel cools and contracts very rapidly, and to a large degree independent of the ground coat and of the steel. So likewise is the contraction of the ground coat partly independent of the steel and cover enamel, and the contraction of the steel independent of both coats of enamel. If there is any deficiency in the bond between the ground coat and the steel, or between the different coats of enamel it will certainly present itself under these conditions. If the coefficient of expansion of the enamels and the steel are very different that fact will also present itself here, causing the enamel to fly off. Cooking utensils are especially required to be able to withstand such treatment, as the ware will be taken off of the stove, possibly after having boiled dry and become very hot, and immediately placed under the hydrant and cold water run into it.

Impact.

A very large percent of enamel ware is destroyed by the enamel being knocked off, and subsequent rusting of the exposed steel.

These wares differ very widely with regard to their ability to resist impact without shattering, and it is too frequently the case that ware is placed on the market which, when subjected to a slight blow, shatters so badly as to render it useless. The nature of the rupture produced when this ware is subjected to blows determines very largely the future usefulness of the ware. If the ground

coat comes off with the cover enamel, leaving the steel exposed, it is only a matter of a few days until the steel rusts through. On the other hand, if the cover enamel breaks off, leaving the ground coat intact, the ware will probably last a long time without further harm.

TESTING THESE WARES.

The tests made by Prof. Orton developed the fact that chemical and physical excellence in this ware are neither mutually dependent nor mutually incompatible. Although the results of his chemical tests were entirely consistent throughout, his tests on the physical properties of the ware produced results which were very difficult to interpret, and no relation could be established between the chemical and physical properties of the ware.

In order to thoroughly investigate this proposition it will be necessary to determine what are the factors which affect the chemical and physical properties of enamel, and to establish, if possible, some relation between them.

In outlining a method for attacking this problem the writer has drawn the following conclusions from the statement made concerning the properties of enamels:

1. The chemical tests will deal entirely with the cover enamel, and the result will not be affected by variations in the ground coat or steel.

2. The testing by sudden change of temperature and by impact, or in other words the physical tests, deal with both coats of enamel and the steel, and variations in any of them will affect the results. Not only is the chemical composition of the enamel an important factor, but the gauge of the steel, quality of the steel, thickness of the enamel, time and temperature of burning, workmanship in application, and a number of other factors all have a marked influence on the physical properties of the ware.

No attempt has been made to prove the truth or falsity of these statements, but from experience in producing and handling this ware the writer is led to believe that both are correct.

With these facts as a basis, the work necessary to be done is plain. For the chemical tests it will be necessary to make a series of cover enamels of different chemical composition, and by applying chemical tests determine the facts desired. The physical tests will require a thorough investigation of the ground coat and cover coat and the steel, and the determination of mechanical tests that will show any physical weakness in the ware.

This program, as outlined, will require a great amount of time and labor, and up to the present time the writer has only been able to cover a small part of the field.

THE INVESTIGATION.

The object of this investigation was to devise chemical tests which would be of practical value in classifying enamel ware, and to establish a limit of solubility beyond which enamel ware should be condemned for household purposes, or any other purpose where the ware is likely to be materially affected by the action of chemical agents. At the same time it was desired to determine what variations in the composition of enamels will be required in order to bring them within these limits of solubility, and at the same time maintain their physical properties such as to render them useful.

Since white enamel is nearly always used for lining cooking utensils and vessels for chemical purposes, and also because of the fact that white enamel is likely to be less soluble than colored enamel, it was determined to base this investigation on white enamels.

Having a number of formulae which are known to be in use at present, or at least to have been used in the past for commercial purposes, they were carefully studied to determine what is the general practice in compounding white enamels and about what is their average chemical composition. With this data as a basis, a series of enamels was compounded, following the general lines of Prof. Purdy's investigation of fritted glazes.

The writer fully realizes that the ultimate chemical composition does not tell the whole story; that the properties of these enamels are likely to be affected by varying the source of this ultimate chemical composition, but if the fritting is thorough the chemical properties will be less affected than any other property of the enamel and, after all, the variation in ultimate composition will give more accurate results than any other single method of study.

In order to thoroughly cover the field it will be necessary to make two series of enamels, one in which the bases vary and another in which the O. R., SiO_2, B_2O_3 ratio and Al_2O_3 content vary. The writer had hoped to be able to make up both these series and show the result of chemical tests on them at this time, but the amount of time and work required has been greater than was expected, and hence it has only been possible to complete the investigation of the latter series.

MATERIALS USED.

The materials used in making the enamels were as follows:

$$\left.\begin{matrix} .20\ Na_2O \\ .75\ K_2O \\ .05\ CaO \end{matrix}\right\} 1.15\ Al_2O_3 \left\{\begin{matrix} 8.6\ SiO_2 \\ \\ .1\ H_2O \end{matrix}\right.$$

Equiv. Wt. 770.7

Georgia Kaolin, Al_2O_3, 2.2 SiO_2, 2.2 H_2O	Equiv. Wt.	273.6
Ground Flint, SiO_2	Equiv. Wt.	60.
Fluorspar, CaF_2	Equiv. Wt.	78.
Enamel Soda, Na_2CO_3	Equiv. Wt.	106.
Salt Peter, KnO_3	Equiv. Wt.	202.
Borax, $Na_2B_4O_7$, 10 H_2O	Equiv. Wt.	382.
Boracic Acid, B_2O_3	Equiv. Wt.	70.
Cryolite, Na_3AlF_6	Equiv. Wt.	420.

All chemicals were purchased as pure as could be obtained. The feldspar and flint were analyzed, and all others were given preliminary tests for impurities.

DESIGNING THE SERIES.

The formula selected as a basis for the investigation is as follows:

$$\left.\begin{matrix} .4\ Na_2O \\ .2\ K_2O \\ .4\ CaO \end{matrix}\right\} X\ Al_2O_3 \left\{\begin{matrix} Y\ SiO_2 \\ Z\ B_2O_3 \end{matrix}\right.$$

X, Y and Z are variables, the R O remaining constant. This R O is a little higher in CaO than the average of white enamels, but it was made so in order to insure any of the enamels from solubility because of the R O. White enamels sometimes contain BaO, PbO and ZnO, but for the purpose at hand the R O selected above seems best, and at the same time it will give good results.

The average white formula is about as follows:

$$\left.\begin{matrix} .5\ Na_2O \\ .2\ K_2O \\ .3\ CaO \end{matrix}\right\} .15\ Al_2O_3 \left\{\begin{matrix} 1.7\ SiO_2 \\ .4\ B_2O_3 \end{matrix}\right.$$

O. R. 3.2

$SiO_2 : B_2O_3$ 4.3

Of course there are many varietions in composition which this does not include, some formulae containing P_2O_5, Sb_2O_3, PbO, BaO and ZnO, but they are rather the exception than the rule.

The formulae given here are the formulae of the fritt. All white enamels contain from 5 to 12% of raw material consisting of clay and tin oxide, and sometimes MgO and other substances which serve to float the glaze. These raw materials are not included in any of the formulae because they remain in an uncombined state after the enamel is burnt, and if the amount added to each enamel is constant, their effect on the solubility of all enamels will be practically the same.

In the following series the O. R. varies from 2.5 to 5.0, SiO_2, B_2O_3 ratio varies from 3 to 7 and Al_2O_3 content varies from .1 to .4 equivalent.

The method of numbering has been so selected that the number of the enamel tells its composition except as regards O. R.; for instance, number 342 has O. R. 3.5, $SiO_2 : B_2O_3 = 4 : 1$, $Al_2O_3 = .2$ Eqv.

The Series.

No.	O. R	B_2O_3: SiO_2	Al_2O_3
131	2.5	1:3	.1
132	2.5	1:3	.2
133	2.5	1:3	.3
134	2.5	1:3	.4
141	2.5	1:4	.1
142	2.5	1:4	.2
143	2.5	1:4	.3
144	2.5	1:4	.4
151	2.5	1:5	.1
152	2.5	1:5	.2
153	2.5	1:5	.3
154	2.5	1:5	.4
161	2.5	1:6	.1
162	2.5	1:6	.2
163	2.5	1:6	.3
164	2.5	1:6	.4
171	2.5	1:7	.1
172	2.5	1:7	.2
173	2.5	1:7	.3
174	2.5	1:7	.4
231	3	1:3	.1
232	3	1:3	.2
233	3	1:3	.3
234	3	1:3	.4
241	3	1:4	.1
242	3	1:4	.2
243	3	1:4	.3
244	3	1:4	.4
251	3	1:5	.1
252	3	1:5	.2
253	3	1:5	.3
254	3	1:5	.4
261	3	1:6	.1
262	3	1:6	.2
263	3	1:6	.3
264	3	1:6	.4
271	3	1:7	.1
272	3	1:7	.2
273	3	1:7	.3
274	3	1:7	.4
331	3.5	1:3	.1
332	3.5	1:3	.2
333	3.5	1:3	.3
334	3.5	1:3	.4
341	3.5	1:4	.1
342	3.5	1:4	.2
343	3.5	1:4	.3
344	3.5	1:4	.4
351	3.5	1:5	.1
352	3.5	1:5	.2
353	3.5	1:5	.3

No.	O. R.	B_2O_3: SiO_2	Al_2O_3
354	3.5	1:5	.4
361	3.5	1:6	.1
362	3.5	1:6	.2
363	3.5	1:6	.3
364	3.5	1:6	.4
371	3.5	1:7	.1
372	3.5	1:7	.2
373	3.5	1:7	.3
374	3.5	1:7	.4
431	4	1:3	.1
432	4	1:3	.2
433	4	1:3	.3
434	4	1:3	.4
441	4	1:4	.1
442	4	1:4	.2
443	4	1:4	.3
444	4	1:4	.4
451	4	1:5	.1
452	4	1:5	.2
453	4	1:5	.3
454	4	1:5	.4
461	4	1:6	.1
462	4	1:6	.2
463	4	1:6	.3
464	4	1:6	.4
471	4	1:7	.1
472	4	1:7	.2
473	4	1:7	.3
474	4	1:7	.4
531	4.5	1:3	.1
532	4.5	1:3	.2
533	4.5	1:3	.3
534	4.5	1:3	.4
541	4.5	1:4	.1
542	4.5	1:4	.2
543	4.5	1:4	.3
544	4.5	1:4	.4
551	4.5	1:5	.1
552	4.5	1:5	.2
553	4.5	1:5	.3
554	4.5	1:5	.4
561	4.5	1:6	.1
562	4.5	1:6	.2
563	4.5	1:6	.3
564	4.5	1:6	.4
571	4.5	1:7	.1
572	4.5	1:7	.2
573	4.5	1:7	.3
574	4.5	1:7	.4
631	5	1:3	.1
632	5	1:3	.2
633	5	1:3	.3

No.	O R.	B_2O_3:SiO_2	Al_2O_3
634	5	1:3	.4
641	5	1:4	.1
642	5	1:4	.2
643	5	1:4	.3
644	5	1:4	.4
651	5	1:5	.1
652	5	1:5	.2
653	5	1:5	.3
654	5	1:5	.4
661	5	1:6	.1
662	5	1:6	.2
663	5	1:6	.3
664	5	1:6	.4
671	5	1:7	.1
672	5	1:7	.2
673	5	1:7	.3
674	5	1:7	.4

Equivalent Formulae.

No.	R. O.	Al_2O_3	SiO_2	B_2O_3
131	1.0	.1	1.083	.361
132	1.0	.2	1.332	.444
133	1.0	.3	1.581	.527
134	1.0	.4	1.883	.611
141	1.0	.1	1.180	.295
142	1.0	.2	1.452	.363
143	1.0	.3	1.724	.431
144	1.0	.4	2.000	.500
151	1.0	.1	1.250	.250
152	1.0	.2	1.535	.307
153	1.0	.3	1.825	.365
154	1.0	.4	2.115	.423
161	1.0	.1	1.296	.216
162	1.0	.2	1.596	.266
163	1.0	.3	1.896	.316
164	1.0	.4	2.196	.366
171	1.0	.1	1.337	.191
172	1.0	.2	1.645	.235
173	1.0	.3	1.953	.279
174	1.0	.4	2.261	.323
231	1.0	.1	1.299	.433
232	1.0	.2	1.599	.533
233	1.0	.3	1.899	.633
234	1.0	.4	2.199	.733
241	1.0	.1	1.416	.354
242	1.0	.2	1.744	.436

No.	R. O.	Al_2O_3	SiO_2	B_2O_3
243	1.0	.3	2.072	.518
244	1.0	.4	2.400	.600
251	1.0	.1	1.500	.300
252	1.0	.2	1.845	.369
253	1.0	.3	2.190	.438
254	1.0	.4	2.535	.507
261	1.0	.1	1.560	.260
262	1.0	.2	1.920	.320
263	1.0	.3	2.280	.380
264	1.0	.4	2.640	.440
271	1.0	.1	1.603	.229
272	1.0	.2	1.974	.282
273	1.0	.3	2.345	.335
274	1.0	.4	2.716	.388
331	1.0	.1	1.515	.505
332	1.0	.2	1.866	.622
333	1.0	.3	2.217	.739
334	1.0	.4	2.565	.855
341	1.0	.1	1.652	.413
342	1.0	.2	2.036	.509
343	1.0	.3	2.416	.604
344	1.0	.4	2.800	.700
351	1.0	.1	1.750	.350
352	1.0	.2	2.150	.430
353	1.0	.3	2.555	.511
354	1.0	.4	2.960	.592
361	1.0	.1	1.818	.303
362	1.0	.2	2.238	.373
363	1.0	.3	2.658	.443
364	1.0	.4	3.078	.513
371	1.0	.1	1.869	.267
372	1.0	.2	2.303	.329
373	1.0	.3	2.737	.391
374	1.0	.4	3.171	.453
431	1.0	.1	1.740	.580
432	1.0	.2	2.133	.711
433	1.0	.3	2.532	.844
434	1.0	.4	2.931	.977
441	1.0	.1	1.188	.472
442	1.0	.2	2.324	.581
443	1.0	.3	2.760	.690
444	1.0	.4	3.200	.800
451	1.0	.1	2.000	.400
452	1.0	.2	2.460	.492
453	1.0	.3	2.920	.584
454	1.0	.4	3.380	.676
461	1.0	.1	2.076	.343
462	1.0	.2	2.566	.426
463	1.0	.3	3.036	.506
464	1.0	.4	3.516	.586
471	1.0	.1	2.135	.305
472	1.0	.2	2.632	.376

No.	R O	Al_2O_3	SiO_2	B_2O_3
473	1.0	.3	3.129	.447
474	1.0	.4	3.626	.518
531	1.0	.1	1.950	.650
532	1.0	.2	2.400	.800
533	1.0	.3	2.850	.950
534	1.0	.4	3.300	1.100
541	1.0	.1	2.124	.531
542	1.0	.2	2.616	.654
543	1.0	.3	3.108	.777
544	1.0	.4	3.600	.900
551	1.0	.1	2.250	.450
552	1.0	.2	2.765	.553
553	1.0	.3	3.285	.657
554	1.0	.4	3.005	.761
561	1.0	.1	2.340	.390
562	1.0	.2	2.880	.480
563	1.0	.3	3.420	.570
564	1.0	.4	3.960	.660
571	1.0	.1	2.408	.344
572	1.0	.2	2.961	.423
573	1.0	.3	3.514	.503
574	1.0	.4	4.074	.582
631	1.0	.1	2.166	.722
632	1.0	.2	2.664	.888
633	1.0	.3	3.165	1.055
634	1.0	.4	3.666	1.222
641	1.0	.1	2.360	.590
642	1.0	.2	2.908	.727
643	1.0	.3	3.452	.863
644	1.0	.4	4.000	1.000
651	1.0	.1	2.500	.500
652	1.0	.2	3.075	.615
653	1.0	.3	3.650	.730
654	1.0	.4	4.225	.845
661	1.0	.1	2.598	.433
662	1.0	.2	3.198	.533
663	1.0	.3	3.798	.633
664	1.0	.4	4.398	.733
671	1.0	.1	2.674	.382
672	1.0	.2	3.290	.470
673	1.0	.3	3.906	.558
674	1.0	.4	4.522	.646

Batch Equivalents.

No.	Spar	Flint	Borax	Soda	KNO_3	CaF_2	Cryolite	B_2O_3
131	0	1.583	.100	0	.2	.4	.1	.161
132	.087	.082	.083	0	.035	.396	.1	.268
133	.174	.580	.065	0	.070	.391	.1	.397
134	.174	.662	.065	Clay .1	.070	.391	.1	.481
141	0	1.680	.100	0	.2	.400	.1	.095
142	.087	1.202	.083	0	.135	.396	.1	.197
143	.174	.723	.065	0	.070	.391	.1	.301
144	.174	.780	.065	.100	.070	.391	.1	.370
151	0	1.750	.100	0	.2	.400	.1	.050
152	.087	1.285	.083	0	.135	.396	.1	.141
153	.174	.823	.065	0	.070	.391	.1	.235
154	.174	.894	.065	.100	.070	.391	.1	.293
161	0	1.796	.100	0	.2	.400	.1	.016
162	.087	1.346	.083	0	.135	.396	.1	.100
163	.174	.895	.065	0	.070	.391	.1	.176
164	.174	.973	.065	.1	.070	.391	.1	.220
171	0	1.837	.095	Soda .005	.200	.400	.1	.000
172	.087	1.395	.083	.000	.135	.396	.1	.069
173	.174	.953	.065	.000	.070	.391	.1	.149
174	.174	1.040	.065	Clay .1	.070	.391	.1	.193
231	0	1.799	.100	0	.135	.396	.1	.233
232	.087	1.349	.083	0	.200	.400	.1	.367
233	.174	.898	.065	0	.070	.391	.1	.503
234	.174	.978	.065	.1	.070	.391	.1	.603
241	0	1.916	.100	0	.200	.400	.1	.154
242	.087	1.490	.083	0	.135	.396	.1	.270
243	.174	1.071	.065	0	.070	.391	.1	.388
244	.174	1.179	.065	.1	.070	.391	.1	.470
251	0	2.00	.1	0	.2	.4	.1	.1
252	.087	1.595	.083	0	.135	.396	.1	.203
253	.174	1.189	.065	0	.070	.391	.1	.308
254	.174	1.314	.065	.1	.070	.391	.1	.377
261	0	2.060	.1	0	.2	.4	.1	.060
262	.087	1.670	.083	0	.135	.396	.1	.154
263	.174	1.279	.065	0	.070	.391	.1	.250
264	.174	1.419	.065	.1	.070	.391	.1	.310
271	0	2.103	.100	0	.200	.400	.1	.029
272	.087	1.724	.083	0	.135	.396	.1	.116
273	.174	1.344	.065	0	.070	.391	.1	.205
274	.174	1.495	.065	.1	.070	.391	.1	.258
331	0	2.015	.1	0	.200	.400	.1	.305
332	.087	1.615	.083	0	.135	.396	.1	.459
333	.174	1.216	.065	0	.070	.391	.1	.609
334	.174	1.344	.065	.1	.070	.391	.1	.725
341	0	2.152	.1	0	.200	.400	.1	.213
342	.087	1.786	.083	0	.135	.396	.1	.343
343	.174	1.415	.065	0	.070	.391	.1	.474
344	.174	1.579	.065	.1	.070	.391	.1	.570
351	0	2.250	.100	0	.200	.400	.1	.150

No.	Spar	Flint	Borax	Soda Clay	KNO_3	CaF_2	Cryolite	B_2O_3
352	.087	1.900	.083	0	.135	.396	.1	.264
353	.174	1.554	.065	0	.070	.391	.1	.381
354	.174	1.739	.065	.1	.070	.391	.1	.462
361	0	2.318	.100	0	.200	.400	.1	.103
362	.087	1.988	.083	0	.135	.396	.1	.207
363	.174	1.657	.065	0	.070	.391	.1	.313
364	.174	1.857	.065	.1	.070	.391	.1	.383
371	0	2.369	.1	0	.200	.400	.1	.067
372	.087	2.053	.083	0	.135	.396	.1	.163
373	.174	1.736	.065	0	.070	.391	.1	.261
374	.174	1.950	.065	.1	.070	.391	.1	.323
431	0	2.240	.100	0	.2	.400	.1	.380
432	.087	1.883	.083	0	.135	.396	.1	.545
433	.174	1.531	.065	0	.070	.391	.1	.714
434	.174	1.710	.065	.1	.070	.391	.1	.847
441	0	2.388	.1	0	.2	.4	.1	.272
442	.087	2.074	.083	0	.135	.396	.1	.415
443	.174	1.759	.065	0	.070	.391	.1	.560
444	.174	1.979	.065	.1	.070	.391	.1	.670
451	0	2.500	.1	0	.2	.4	.1	.200
452	.087	2.210	.083	0	.135	.396	.1	.326
453	.174	1.919	.065	0	.070	.391	.1	.454
454	.174	2.159	.065	.1	.070	.391	.1	.546
461	0	2.576	.1	0	.2	.4	.1	.146
462	.187	2.306	.083	0	.135	.396	.1	.260
463	.174	2.035	.065	0	.070	.391	.1	.376
464	.174	2.295	.065	.1	.070	.391	.1	.456
471	0	2.635	.1	0	.2	.4	.1	.105
472	.087	2.382	.083	0	.135	.396	.1	.210
473	.174	2.128	.065	0	.070	.391	.1	.317
474	.174	2.405	.065	.1	.070	.391	.1	.388
531	0	2.450	.1	0	.2	.4	.1	.450
532	.087	2.150	.083	0	.135	.396	.1	.634
533	.174	1.849	.065	0	.070	.391	.1	.820
534	.174	2.079	.065	.1	.070	.391	.1	.970
541	0	2.634	.1	0	.2	.4	.1	.331
542	.087	2.366	.083	0	.135	.396	.1	.488
543	.174	2.107	.065	0	.070	.391	.1	.647
544	.174	2.379	.065	.1	.070	.391	.1	.770
551	0	2.750	.1	0	.2	.4	.1	.250
552	.087	2.515	.083	0	.135	.396	.1	.387
553	.174	2.284	.065	0	.070	.391	.1	.527
554	.174	2.584	.065	.1	.070	.391	.1	.631
561	0	2.840	.1	0	.2	.4	.1	.190
562	.087	2.630	.083	0	.135	.396	.1	.314
563	.174	2.419	.065	0	.070	.391	.1	.440
564	.174	2.739	.065	.1	.070	.391	.1	.530
571	0	2.908	.1	0	.2	.4	.1	.144
572	.087	2.711	.083	0	.135	.396	.1	.257
573	.174	2.513	.065	0	.070	.391	.1	.372
574	.174	2.853	.065	.1	.070	.391	.1	.452
631	0	2.666	.1	0	.2	.4	.1	.522
632	.087	2.414	.083	0	.135	.396	.1	.722

No.	Spar	Flint	Borax	Soda Clay	KNO_3	CaF_2	Cryolite	B_2O_3
633	.174	2.164	.065	0	.070	.391	.1	.925
634	.174	2.445	.065	.1	.070	.391	.1	1.092
641	0	2.860	.1	0	.2	.4	.1	.390
642	.087	2.658	.083	0	.135	.396	.1	.561
643	.174	2.451	.065	0	.070	.391	.1	.733
644	.174	2.779	.065	.1	.070	.391	.1	.870
651	0	3.000	.1	0	.2	.4	.1	.3
652	.087	2.825	.083	0	.135	.396	.1	.449
653	.174	2.649	.065	0	.070	.391	.1	.600
654	.174	3.004	.065	.1	.070	.391	.1	.715
661	0	3.098	.1	0	.2	.4	.1	.233
662	.087	2.948	.083	0	.135	.396	.1	.367
663	.174	2.797	.065	0	.070	.391	.1	.503
664	.174	3.177	.065	.1	.070	.391	.1	.603
671	0	3.174	.1	0	.2	.4	.1	.182
672	.087	3.040	.083	0	.135	.396	.1	.304
673	.174	2.905	.065	0	.070	.391	.1	.428
674	.174	3.301	.065	.1	.070	.391	.1	.516

PREPARING THE ENAMELS.

Fritting.

One grain equivalent of each enamel was carefully weighed and thoroughly mixed by passing through a screen several times. They were then fritted in Hessian crucibles in an experimental frit furnace using artificial gas for fuel, burned with compressed air. The temperature of the frit furnace was not measured but it ran quite constant, as it was heated and kept going day and night until all fritting was completed. The length of time required to frit each enamel was about one hour, although it varied some, depending on the composition of the enamel.

Grinding.

The enamels were ground dry in 8″ porcelain mills to pass through an 80 mesh screen. Before placing in the mill there was added to each enamel 5% plastic clay and 7% tin oxide.

Slushing.

The test pieces used were rectangular pieces of 20 gauge steel 1½″x 3″. Each sample was coated on both

sides with a good reliable ground coat, care being taken in slushing and burning to see that the edges remained coated with enamel.

Half of each enamel batch was placed in a bottle, mixed with about 50% water, or sufficient to give an enamel of proper consistency for slushing, and thoroughly shaken. It was then placed in a dish of appropriate shape and size for slushing. Seven samples were coated with each enamel. Two coats of white were applied to each sample on both sides. After slushing, the samples were immediately placed in a dryer and left until perfectly dry.

Burning.

The time and temperature of burning was varied to suit the different enamels. Some enamels required higher temperature and longer time in the muffle than others. The object was to produce the very best piece of ware that could be produced with each enamel. At the same time every precaution was taken to keep the edges of the samples covered with enamel. In the main, the results were entirely satisfactory. The temperature of the muffle was measured with a pyrometer. The temperature used for burning varied from 1500 to 1800 degrees F, increasing with increase of OR and Al_2O_3 and decrease of B_2O_3.

TESTING THE SAMPLES.

It seems to the writer that the work done by Prof. Orton on this subject established very definitely the fact that different enamels will show the same relative solubility when exposed to different inorganic acids. Of course the strength and temperature of the acid and the time of the exposure will greatly influence the absolute solubility of any given enamel but, comparatively, the results will be the same regardless of what acid is used. Therefore, for this investigation, it was deemed sufficient to select arbitrarily a particular acid, its strength and the temperature and the time of the exposure.

Just which acid is best for testing enamels is a debatable question. The Hooper method, as described by Prof. Orton, has objectionable features which, it seems to the writer, make it impracticable for this purpose. Unless every piece of ware tested by this method is of exactly the same shape and size, it is of absolutely no value for comparing enamel wares. Suppose you have two pieces of ware—one a large vessel of large area of bottom, the other a high vessel of small area of bottom. It will take much longer to evaporate 500 c. c. of the same strength acid out of the latter than the former, hence more solubility of the latter. The method is also open to the objection of probable change in strength of the acid during boiling. The cleaning the surface after boiling by scouring with sand or sapolio is entirely wrong, as in the case of soft enamels this alone will destroy the gloss.

It is possible that acetic acid could be used for testing enamels with good results, but the method of using it as suggested by Mr. Hooper could not be accepted as productive of good results without further proof.

To the writer it seems that acetic is not the proper acid for this purpose. We are dealing here with an inorganic compound and it should be tested with inorganic acids. Although, as a rule, this ware is subjected to the action of organic acids much more than inorganic acids, still it is by no means uncommon that it is subjected to the action of weak solutions of inorganic acids and, as will be shown later, a very weak solution of an inorganic acid has a much greater effect on enamels than a very strong solution of an organic acid.

For testing these enamels two acids were used in order to compare the results. A sample of each enamel was boiled for 15 minutes in 1% solution of H_2SO_4 and the operation repeated on a new sample for accuracy. Another sample of each enamel was boiled for 20 minutes in a 75% solution of acetic acid and the operation repeated on a new sample.

BOILING THE SAMPLES.

After having weighed each sample accurately to .001 gram, they were placed in a vessel of distilled water and the water heated to boiling. The H_2SO_4 solution, having been accurately measured to make a 1% solution of acid, using distilled water and concentrated acid, was also heated to boiling. The samples were now taken out of the boiling water and placed in the boiling acid. This precaution was taken in order to insure no loss in weight from the enamel peeling off because of cold samples being thrown in boiling acid. As soon as the samples had boiled for 15 minutes they were placed in hot water and cold water run in to insure gradual cooling. They were now thoroughly washed in distilled water by gentle rubbing with a soft cloth. After drying, they were again accurately weighed. The difference in weight represents loss due to solution. Each sample having an area of 9 sq. inches, the total loss divided by 9 represents the loss per square inch of exposed surface. The operation with the acetic acid was exactly the same as with the H_2SO_4.

SUDDEN CHANGE OF TEMPERATURE.

No attempt has been made to formulate any definite rule for testing ware by this method, but it was desired to ascertain which of these enamels are likely to prove satisfactory in other respects beside in their chemical properties, hence they were tested by this method as follows:

One sample of each enamel was heated in the muffle to 1500 degrees F. and then allowed to cool just below redness, and while at this temperature they were thrown into water at 60 degrees F. This test was repeated twice, each test being made a little more severe than the preceding one. In the last test, the samples were thrown in the water while they were still red hot and the enamel soft. The second and third tests of this kind were too severe, very few of the test pieces standing them without a great deal of enamel coming off. The first test was quite satisfactory.

DATA.

The following diagram contains all the data obtained. Each square represents a certain enamel as indicated. The upper decimal indicates the loss in grams per square inch of exposed area when exposed to H_2SO_4 as before described.

The lower decimal fraction represents the loss in grams per square inch of exposed area when exposed to acetic acid.

The figure 1, 2 or 3 indicates that the enamel stood the change of temperature test without harm.

The letter "G" indicates that the enamel retained its gloss after the acetic acid treatment.

The letter "X" indicates that no good results were obtained with the enamel thus marked. Those with low O. R. marked thus showed no gloss at any time, although they were burned smooth. Those with high O. R. marked thus showed some gloss, but were rough and could not be burned to a smooth coating.

In interpreting the results of this test on automobile tags, Prof. Orton based his comparisons on the percentage of weight lost by the tags when subjected to the same acid treatment. The writer has the greatest respect for Prof. Orton's ability, and hesitates to question his judgment in this matter, but it seems quite obvious that this basis for comparison is wrong and will lead to contradictory results. For instance, suppose we have two pieces of ware, both containing the same surface area, one of 18 gauge steel with a ground coat, two coats of white and a coat of blue, all heavy coats. The other 20 gauge but all light coats of enamel. Obviously the latter tag will be much the lighter of the two. Now if the same enamel is used on each tag it is likely that on going through the same acid treatment the actual amount dissolved will be practically the same, but the percent of weight lost will be quite different. Hence it seems that it would be more accurate to base this comparison on the absolute loss per unit of exposed area.

$SiO_2 : B_2O_3 = 3:1$

Al_2O_3						
.4	.015 .005 1	.015 .004 1 3	.010 .004 g 1	.009 .005 g ×	.008 .005 g	.009 .004 g 2 ×
.3	.014 .006	.013 .006 2	.012 .005 g	.008 .001 g 1	.007 .001 g 1	.007 .003 g 1 2
.2	.023 .016	.015 .007	.011 .005 2	.011 .003 g 1 2	.008 .003 g 1	.007 .003 g
.1	.025 .012 ×	.033 .013 ×	.016 .006	.013 .003	.013 .007 2	.009 .005 g 1 2
O. R.	2.5	3.0	3.5	4.0	4.5	5.0

A D C B

$SiO_2 : B_2O_3 = 4:1$

Al_2O_3						
.4	.012 .005 1 3	.009 .007 1 3	.008 .004	.008 .004 g	.007 .004 g	.008 .008 g 2 ×
.3	.013 .003 1	.011 .005 1	.010 .005 1	.007 .003 g 1 2	.006 .002 g 1	.008 .006 g 2
.2	.017 .007	.013 .008	.010 .005 g 1	.009 .004 g 1	.008 .003 g 1	.007 .003 g 1 2
1	.010 .006 1	.008 .006	.009 .005	.009 .005	.008 .003	.012 .007 g
O. R.	2.5	3.0	3.5	4.0	4.5	5.0

A D B C

$SiO_2 : B_2O_3 = 5:1$

Al_2O_3	A		D			
.4	.012 .006 1	.010 .005 1	.008 .003 g 1 3	.009 .003 g	.010 .007 g	.011 .006 g
.3	.012 .003	.009 .005 1 3	.008 .003 1 2 3	.007 .001 g 1	.012 .006 g	.010 .005 g
.2	.015 .011 ×	.012 .006	.011 .004 g 1	.008 .007 g 1 3	.007 .002 g 1	.006 .003 g 1 3
.1	.015 .009 ×	.015 .009 ×	.009 .005	.009 .005	.009 .005	.008 .003 g
			B			C
O. R.	2.5	3.0	3.5	4.0	4.5	5.0

$SiO_2 : B_2O_3 = 6:1$

Al_2O_3	A		D			
.4	.009 .003 1 2	.008 .002 1	.007 .008 g 1	.008 .004 g 3	.007 .003 g	.008 .009 g 2 3
.3	.011 .006	.010 .006 1 2	.009 .001 g 1	.006 .002 g 1	.007 .003 g	.008 .007 g 3
.2	.014 .008 ×	.012 .005	.009 .002 g 1 2	.008 .004 g 1 2	.007 .003 g 1 2	.006 .003 g 2
.1	.015 .009 ×	.014 .007 ×	.011 .007	.010 .005 2	.008 .002 2	.007 .004 g 1 2
			B			C
O. R.	2.5	3.0	3.5	4.0	4.5	5.0

$SiO_2 : B_2O_3 = 7:1$

Al_2O_3	A		D			
.4	.008 .002 1 2	.007 .002 1	.006 .003 g 1	.010 .007 g	.011 .005 g 2 ×	.016 .009 g ×
.3	.012 .006 3	.010 .005 1 3	.008 .003 g 1 2	.006 .002 g 1	.011 .003 g	.016 .006 g 2
.2	.012 .005 2	.011 .003	.008 .003 g 1 2	.008 .005 g 1	.007 .004 g	.010 .004 g 1
.1	.016 .010 3 ×	.015 .008 ×	.010 .006	.009 .006 2	.008 .003 g 2	.006 .002 g 1 2
			B			C
O. R.	2.5	3.0	3.5	4.0	4.5	5.0

INTERPRETATION OF THE RESULTS.

Solubility in H_2SO_4.

A study of the diagrams shows:

1. Everything else being constant, the solubility decreases directly as the O. R. increases.

2. Everything else being constant, the solubility decreases as the contents of Al_2O_3 increases.

3. Everything else being constant, the solubility decreases as the B_2O_3 decreases.

Solubility in Acetic Acid.

The results of the acetic acid test are not so sharply defined as in the H_2SO_4 test, but in general the statements made concerning solubility in H_2SO_4 also hold true with regard to acetic acid. One fact is very plain and unmistakable, viz., 75% solution of acetic acid has very much

less solvent action on enamels than has a 1% solution of H_2SO_4. This is indicated not only by the very low loss per square inch in weight, but by the fact that so many samples retain their gloss after the acetic acid treatment, while not one of the enamels showed any gloss after H_2SO_4 treatment. The gloss was affected to some extent on all samples by the acetic acid, but the effect on those high in O. R. and Al_2O_3 was very slight indeed.

After careful study of the data obtained, as well as the action of the enamels in application and burning and the general quality of the results obtained, the writer has outlined the field within which good results can be obtained, and at the same time keep the ware safe from probable destruction by any acid which is likely to be encountered.

The area included in the figure A B C D includes those enamels which did not lose more than .008 gram per square inch of exposed area when treated with H_2SO_4. Every enamel within this area retains its gloss to a high degree after acetic acid treatment as described, with a few exceptions. Every enamel within this area stood at least one of the tests by change of temperature, with a few exceptions.

The enamels below the line A B are ruled out chiefly because of their solubility in H_2SO_4, although a few of them showed no good results at any time.

Those enamels above the line C D are ruled out because of their tendency to chip off, and some of them did not show good results at any time. The high loss which some of these show is due to their chipping off and not due to solution in acids.

CONCLUSIONS.

Correlation of the foregoing data leads to the following conclusions:

1. An enamel which does not lose more than .008 gram per square inch of exposed area during 15 minutes

boiling in 1% solution H_2SO_4 is perfectly safe from destruction from any inorganic acid which it is likely to meet, and will give good service as far as its freedom from solubility is concerned, if used for any of the ordinary purposes for which this ware is used.

2. The enameler has a large field within which he can keep the solubility of his ware within this figure, and yet produce good serviceable ware.

Therefore, the writer believes that the public should reject any ware which shows a solubility higher than .008 gram per square inch when tested in H_2SO_4, as described in this paper, providing the ware is to be used for cooking purposes or any other purpose in which it is essential that the ware be kept clean, and in which it will be subjected to the action of acids to any marked extent.

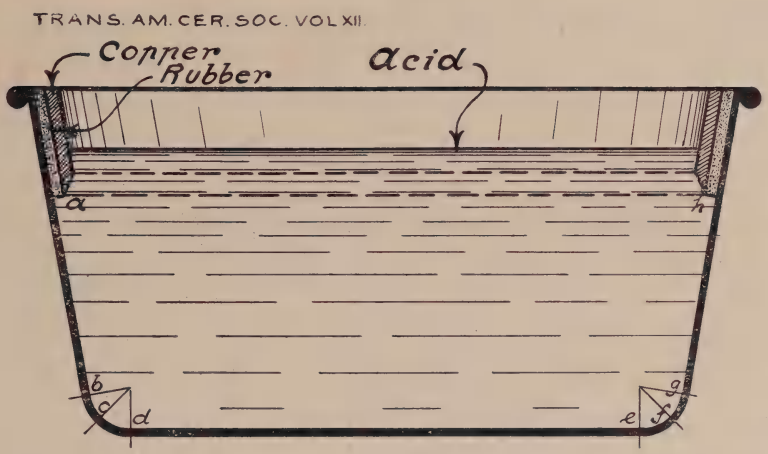
In conclusion, the writer wishes to publicly thank the Grand Rapids Refrigerator Co. for their assistance in furthering this investigation, by furnishing equipment and materials such as were necessary.

PROPOSED STANDARD SOLUBILITY TEST FOR ENAMELED SHEET-STEEL COOKING UTENSILS.

Samples.

Select, as representing the different brands to be tested, pieces of the same shape and size as nearly as possible, and of such a shape that the area of the inside admits of easy and exact measurement by the process described later. The preferable capacity of the test pieces is from one to two quarts.

Preparation of the Samples. Wash each vessel perfectly clean with distilled water, and after drying weigh accurately to 0.001 gram. Then fit a rubber gasket into each vessel, as shown in the diagram below:



The ring holding the gasket in place should be of copper or heavy enameled iron. The gasket must fit firmly against the pan, so as to exclude acid from working up behind it. If necessary, use an expansible ring, which will bring pressure against the gasket to insure its being watertight.

The Solvent. Prepare a mixture of one part by weight of chemically pure sulphuric acid, sp. gr. 1.84, and ninety-nine parts by weight of distilled water, making up a quantity sufficient for the tests to be run through at one time. This must be kept in glass or stoneware containers until needed.

The Process of Testing. After fitting the gasket and ring into one of the vessels to be tested, fill the vessel with water and heat to boiling. In a glass or stoneware receptacle heat a sufficient quantity of the acid solvent. When both fluids are at full boil, pour out the water and immediately pour in the boiling acid to the pan to be tested, filling it above the level of the bottom of the rubber gasket, as shown in the figure. This change should require but a very few seconds. Turn up the flame and boil vigorously for fifteen minutes. If the acid is evaporated so as to fall

below the bottom of the gasket, replenish with a fresh supply.

At the expiration of fifteen minutes pour out the acid and throw it away. Use fresh acid for the next test. Fill the pan with boiling water, and then run in cold water until the pan is cool. Remove the gasket and ring, wash the pan thoroughly in distilled water, rubbing the surface with a cloth, after which dry and weigh the dish carefully. The difference in weight represents the enamel taken into solution, unless it has suffered mechanical loss by chipping, or it has cracked and allowed the acid to attack the surface of the iron underneath. In these events, throw out the test and repeat with a sound vessel.

Determination of Exposed Area.

After the pan has been dried and weighed the last time, cut a straight strip of thin paper about 3-16″ wide, and long enough to reach across the bottom and up the sides of the pan. Paste the strip across the middle of the bottom and up both sides of the pan, using paste which will admit of the paper being taken off easily without tearing.

With the paper in position, mark the points a b d e g h.

a and h will usually be readily seen by the abrupt change in gloss. b, d, e and g are the points where the bottom and sides are tangent to the fillet.

Now subdivide b d and e g, determining points c and f. Now measure the distance c f, b g and a h. Remove the paper and straighten out and measure distances ab, gh, d e, b d and e g.

If the pan is symmetrical,

$$a\,b = h\,g$$
$$b\,d = e\,g$$

If the pan is not symmetrical their averages must be taken.

Then $\frac{a\,b+h\,g}{2}$ = slant height of frustrum of a cone H.

e d = diameter of bottom = D.

c f (measured inside the pan) = diameter of field circle = D′.

Hence-$\frac{b\,d+e\,g}{2}$ = width of fillet = W.

Therefore, $\pi \cdot (\frac{D}{2})^2$= area of bottom, and $\pi \cdot D' \cdot W$ = area of fillet, and $\frac{\pi\,(a\,h+b\,g)}{2} \times H$ = area of sides of pan.

Assembling terms, we have the formula:

$$\pi \left[\frac{D}{2}^2 + D' \cdot W + \left(\frac{a\,h+b\,g}{2}\right) \cdot H\right] = \text{total exposed area.}$$

which will give the desired result very closely.[1]

Final Result. The total loss in weight in grams divided by the exposed area gives the loss per square inch. This loss should not exceed 0.008 gram per square inch, in wares of good quality.

DISCUSSION.

Mr. Price: I am very much interested in this paper. I would like to know the relationship between the solubility and the absorption of the enamel to the failure by impact. We have had some trouble in getting this ware. I noticed he uses No. 20 gauge. This is No. 28 here, and those of American manufacture will invariably crack off when you get at them that way. (Bending the sample.) This is an Austrian shade. There are no cracks in it, while you would get large chunks coming off the American shade. Of course, the steel is rather thin, but I would like to know what Mr. Shaw has to say about this.

Mr. Binns: Is there any sound reason why you should do that way with it?

[1] The fillet in pans is usually very small, never being more than 10% of the total area. The error in figuring the area of the fillet by the method outlined above will never be more than 10%, and the other surfaces are calculated exactly.

This makes a possible error of not more than 1% on the exposed area due to the method of calculation. The laws of Calculus could be applied to determine this area exactly, if the surface was always symmetrical, but there are always irregularities in the surface, and it would be a needless refinement to use calculus under these circumstances.

Mr. Price: Yes; the shade may drop.

Mr. Shaw: Professor Orton was unable to establish any relation between the physical and the chemical properties of the ware, and I hope to test the physical properties of this ware in the future. So far as I know there has been no relation established between the physical and chemical properties of the ware. The statement that invariably the American ware, when treated as you treat this shade, will peel off in large flakes, I think is wrong. I have made an enamel ware that you can bend around a one inch rod and it will straighten right out again.

Mr. Price: Lead me to it.

Mr. Shaw: I have also made an enamel ware that will peel off in large flakes. The secret of the adhering properties of that ware is the thickness of the coat. I made reflectors and I made some that will peel off just as you said that will. And I made some that will hang just as good as that does. So that if you want to produce ware that will match that piece there, you have got to get hold of somebody that knows how to produce it.

Mr. Bruner: It has been customary when making tests on anything to pour acid on it and see what it does. I would like to ask Mr. Shaw if they or anybody else ever tested these wares in an alkaline solution? It would probably be more corrosive than acid. And in addition he said he fired these samples at 15 to 18 hundred degrees Fahrenheit. Is not this temperature somewhat high? In addition, he says some of those samples were plunged immediately while red hot into cold water. What is the object of that, which never occurs in practice?

Mr. Shaw: As to testing in alkalies I never tested these in an alkaline solution, but they would probably be effected by an alkaline solution, I have no doubt of that. The object of these tests was to get at commercial conditions. You do not often find enamel ware subjected to alkaline solutions to any great extent. Cooking solutions are generally acid.

Mr. Binns: Don't you use a little Pearline polish?

Mr. Shaw: It is not that they are never subjected to alkaline solutions; they must stand both, but they are subject to more severe acid than alkaline treatment. So the test with the acid would seem more likely to give accurate commercial results. As the oxygen ratio increases in the test with alkali we would get higher solubility. It is quite apparent that the more acid a substance is, the less easily attacked it is by an acid and the more easily attacked by alkali. In order to get a ware that will stand a severe acid and alkali treatment, there will have to be other considerations than the absolute chemical compositions, as regards acidity. It is probably correct that alkalies will attack this to some extent.

The second question was in regard to temperature. I burn my ground coat at 1800° to 2000° F. I burn the white coat from 1500° to 1700° F., under commercial conditions. If I had burned no higher than 1600°, I would have gotten no enamel at all. The object was to produce the very best piece of ware that could be produced with these enamels, and in order to manufacture them, those that are higher in oxygen ratio and lower in boracic acid had to be burned at a temperature of 1800°. It is by no means impossible to produce good ware at those temperatures—they are not unique at all. The fact is, they are common.

The third question was as to plunging the red hot pieces into cold water. That was a severe test, but wares are subject to treatments approaching that. As I said, kitchen utensils are sometimes boiled dry on the stove and taken off and put under the hydrant and cold water run into them. That approaches the conditions I applied. I only applied it once, however, and the ware would be subjected to the treatment just mentioned 75 or 100 times in the life of the ware.

Mr. Bruner: Another question. How would you carry this out by immersing the entire vessel in the solu-

tion? All vessels have to be supported on forms, where those three points are there is a flaw in the sample. Where do you support them in your experiment to get no flaws?

Mr. Shaw: I support them on enameled iron grates.

Mr. Binns: We have a brother of Mr. Shaw here, and would be glad to hear from him.

Mr. Lucian Shaw: The question as to what you would do to cover the exposed steel, which is unavoidable in practice, I would answer by saying either to cover the points with some insoluble material or leave them exposed to the action of the acid. It is not necessary to have more than three of these exposed points, and they ought not to show more steel than the surface of the head of a pin. We might boil a piece of ware that shows three points for fifteen minutes without materially affecting the results sought.

Mr. Orton: What about the temperature of the furnace?

Mr. Lucian Shaw: We use no pyrometer, but from my observations and the opinions of others who are competent to judge temperatures, we burn our ground coat at 1700° or 1800° F. Our second coat and finish coat, being of a more readily fusible enamel, we burn at from 1400° to 1600° F.

It is possible to burn the softer enamels in the higher temperatures, but to do so requires greater skill and much closer attention on the part of the man who operates the fork.

Mr. Price: I hope that somebody that knows will get that physical and chemical property down, and let us have a paper on it. I was interested in the gauge of the metal and the factor resulting from the different gauges. I wonder if Mr. Shaw can tell me about that. You used No. 20 and we used No. 28.

Mr. Shaw: I have used as high as 18 gauge steel. They use lighter steel, but I do not think they use anything as light as No. 28, though they use some No. 24. My experience has been the heavier the gauge of the steel the

better your enamel will adhere, as a rule.

Mr. Price: Has the Austrian a better steel than we have?

Mr. Shaw: I do not consider the quality or composition of the steel very important. It is to some extent a factor, but I do not think it is a very big one. Of course, you can get bad steel. We received steel two or three weeks ago that developed blisters and you could not use it at all.

SOME NOTES ON POTTERY MOULDS.

BY

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Whether viewing the subject from a technical, or from an economic standpoint, moulds will necessarily claim their share of the attention of every manufacturing potter. This is due to the fact that on the one hand no inconsiderable part of the workmanship and general technical excellence of the finished product is dependent upon the moulds from which it is made; and on the other hand, neglect or even lack of close supervision over this department will always result in direct financial loss. It is as unreasonable to expect to get true, straight ware of uniform thickness and weight from moulds that will not properly fit, or that are of uneven heights in the jigger rings, as it is to expect fair profit from a business conducted along lines of method as extravagant as those which prevail in the mouldshops of some of our potteries today.

And here the writer wishes to protest against the custom in vogue in so many of our clay shops, of throwing away sets of moulds simply because the chief parts are worn out, while other parts of the same set are, perhaps, only half worn. This is more especially the case with pressers' moulds, where handle moulds will do good service twice or three times as long as will the moulds for the body of the piece to which they belong. This will become evident when figures are given in specific cases.

To keep an accurate account of every set of moulds used in the factory does not consume more than one hour each week, but furnishes a close check on how long they last, and from this data the cost of the moulds is easily obtained. The system in use by the writer is as follows:

For every set of moulds brought into the clayshop, an order from the foreman is given to the mouldmaker, stating the quantity of moulds required. At the end of the day these orders are collected, and each set of moulds, giving the quantity, together with the date on which they were put into use, are entered in vertical columns in a book provided for the purpose. Every day the quantity of ware made from each set is entered in its appropriate column, and when the set is worn out, the total number of dozens of ware made from it added, and from this data the quantity of ware made from a single mould is obtained. In a record of this kind, it is very useful to make note of the various conditions that affect the life of the moulds, such as the rate of drying and the brand of plaster used.

The methods employed in the manufacture of pottery plaster have been so well described by Ashley in Vol. X, p. 77, that it is not necessary to dwell upon them here, though it may be well to recall the esential changes undergone in the partial dehydration during manufacture and the subsequent rehydration upon mixture with water. Upon heating the ground gypsum to about 130° C., three-quarters of the chemically combined water is given off, the original substance containing 4 molecules of water to every 2 of calcium sulphate, and the prepared plaster but one molecule of water. Chemically expressed, the dehydration action is as follows:

$$\left\{\begin{matrix} CaSO_4\ 2H_2O \\ CaSO_4\ 2H_2O \end{matrix}\right\} \longrightarrow \left\{\begin{matrix} CaSO_4\ H^1/_2O \\ CaSO_4 \end{matrix}\right\}$$

When plaster is mixed with water it recombines and recrystallizes to form the original compound, gypsum, with 4 molecules of water to every 2 of calcium sulphate.

The hardness of plaster when set depends on its crystalline nature, and this will be retained up to the temperature at which part of the combined water (forming the crystals) is driven off, or, as it is commonly expressed, the moulds are burnt. Their soft and crumbling nature is obviously the result of loss of crystalline structure.

For purposes of classification, pottery moulds may be divided into four classes: those used for Jiggering, Casting, Pressing, and Handle moulds.

Jiggered Moulds.

(*a*) *For Flat Ware* (plates, saucers, etc.).

It is very essential that these should fit the jigger rings properly, be free from all warping, and all be of exactly the same height above the ring. The first qualification is perhaps that most frequently departed from, since proper fitting depends so much upon the proper turning up of the rings. It is a very grave mistake to fit a mould, of which any quantity is to be made, to a jigger ring in actual use; but every mouldshop should contain a complete set of turned iron pattern rings corresponding with all the sizes in use in the pottery. All moulds should then be fitted to these pattern rings which always remain the same, and the working rings turned to fit the moulds. This remark would appear superfluous were it not for the fact that the reverse of the above method is still the rule in some mouldshops.

Even with the most careful fitting to pattern rings, however, moulds will occasionally be found to vary in size, and then the trouble is most likely to be found to lie with the plaster. Ashley (Vol. X, p. 89) has shown that overburned plaster sets very slowly, and this naturally results in an expansion after the moulds have left the cases.

The inevitable variations in blending will give mixings of slightly differing setting properties, and thus with overburned plaster it is not surprising that two moulds made out of the same case will differ more or less in size and consequently in fitting the jigger ring. For this reason the writer considers it very important to avoid slow-setting plaster for making cases, as of course a variation there would affect all the moulds made, even if there were no subsequent expansion in the latter.

It should be made an invariable rule that before mak-

ing a set of moulds, one out of each case should first be taken and tested for size and height in a jigger ring under a fixed gauge, so that if any difference be found between the cases, those showing variation may be set aside. Each of the set of cases should bear its own number so that the moulds may be similarly marked, and any variation in the same be traced to their source in the case.

All flat cases should be bound with heavy hoop-iron,—preferably galvanized—to prevent any enlargement due to swelling of the moulds. It is sometimes the custom to make block moulds a trifle loose for the rings in which they are to run, in order to allow for the slight expansion of the working moulds; but this should not be done, as there appears to be a slight *in*swelling of the cases when they are made, and this offsets the subsequent *out*swelling or expansion of the working moulds.

Variations in the height of moulds above the ring—resulting directly in a corresponding variation in the thickness of the ware made from them—can usually be traced to leaking cases, though this should not occur if they are properly made.

It is very important to thoroughly dry cases before putting them into use, as if used wet they are liable to warp—more particularly the larger plate and machine dish cases—while at the same time care in this direction will save pinching off of any fine embossed work and also save the face of the case.

As regards the life of this class of moulds, the usual figures are from 8 to 12 dozens of ware to the single mould, though if the moulds are thoroughly dried before being put into commission, the life of these moulds should be nearer the upper limit. One factor which materially affects the question is that of allowing the ware to dry completely before filling the moulds again, since the throwing of bats on damp (and consequently soft) moulds has a strong abrasive tendency. Again, the shape of the moulds has considerable influence; those with steep sides such as

outside salads, nappies and coupe-soups, being quickly worn by the pressure due to contraction of the ware in drying.

(*b*) *For Hollow Ware—Single Moulds.*

This includes moulds for such ware as cups, bowls, nappies and machine bakers. As in the case of flat moulds, accuracy of running is essential to first class workmanship, though hardly to the same degree, since a large proportion of this class of ware is lathe turned. Considerable attention should be paid to the height of the mould above the ring in relation to that portion below it, since a good deal of trouble is often experienced by the moulds tipping in the ring under pressure from the jigger tool. The angle of the natch, or part in contact with the ring, will also have considerable effect. Much trouble in the fitting of jiggered moulds will be avoided if a standard bevel for the natches of all moulds be adopted—say 25 degrees from the perpendicular.

In making cases for this class of moulds, it is advisable to strengthen the lower or hump part by insertion of a piece of heavy galvanized hoop-iron.

The life of these moulds varies considerably according to the methods by which the ware is to be finished; if to be sponged, the mould being figured or embossed, 8 to 10 dozen to a mould will be the limit; if to be turned—and the mould is not wearing too fast at the shoulder—15 to 20 dozen and even higher may be obtained from each mould. In one instance, a set of plain inside baker moulds gave a return of over 20 dozen to a mould, and were not worn out even then. In the case of these machine bakers, the ware was at first made off of outside moulds; but owing to considerable loss due to cracking of the ware and wearing out of the moulds, it was decided to use inside moulds. Every advantage was found to be on the side of the latter, —not only increased output and freedom from loss, but the life of the moulds was more than doubled. This was naturally due to the shrinkage being away from the

moulds in the latter case, reducing the abrasive feature to a minimum. In some potteries cup and bowl moulds are greased under the shoulder with a heavy oil as a means of hardening the plaster and preventing abrasion by the jigger ring.

(*c*) *For Hollow Ware—Three and Four Part Moulds.*

Reference is made particularly to those moulds used for making jugs, sugars, etc., though the same remarks hold true of those for the larger ware, such as ewers and slop jars.

These moulds, being very expensive, demand careful consideration as regards their efficiency and wearing qualities. The variation in wear is chiefly due to their shape and the style of their embossed work, if any exists. Generally speaking, a low bulging shape will wear out very much more quickly than a comparatively straight one, owing to the fact that in drying the ware rests on the lower part of the side of the mould in the first case, while the weight is almost entirely on the bottom in the second. While the one would not run over 8 or 10 dozen to the mould—hardly as much if light embossed work were present—the other might show a result of 14 or 16 to the mould.

In making this class of moulds it is important to remove the sides from the cases as soon as possible to avoid binding on, and warping of the cases. An excellent plan —the writer is indebted to Mr. R. J. Meakin for the suggestion—is to make the top cover of the case divided, thus allowing the expansive force of the setting plaster to be exerted upwards as well as sideways, and almost entirely obviating the necessity of scraping the sides of the mould to make them fit in the shell or frame. The same principle may be applied, and with even greater benefit, to the larger hollow ware moulds such as ewers, cabinets, etc.

Cast Moulds.

There are probably several reasons why the process of casting has not found more general favor among the pot-

ters of this country, but none is more obvious than the rapid destruction of the moulds which takes place under the methods at present in use. In the majority of cases, 4, or at most 5 dozen of ware are all that can be obtained from each mould, and since the latter are of the most expensive type, it is evident that here the cost of moulds enters into the total cost of production as quite a large item. Various salts, particularly bicarbonate of soda, which are frequently used in this process, undoubtedly tend to hasten the wearing out of the moulds, and on those grounds their use should not be permitted.

When articles such as creams and small jugs are cast two or three in a mould, it is very essential that the sides of the mould should fit together perfectly to avoid all leakage. In this connection may be suggested the insertion of a piece of iron in the cases to prevent possible warping; and the taking off of the moulds from the case as soon as possible to avoid binding and consequent pinching off of corners.

Pressed Moulds.

Owing in a large measure, no doubt, to the greater care with which pressers' moulds are used, they show more satisfactory figures as regards wear than any yet considered. From 15 to 20 or even 25 dozen of ware to the single mould are often obtained from them, though it most frequently happens that some parts of the same set last longer than others. Thus in the case of pressed jugs, one-half dozen of bottoms will usually wear out one and one-half dozen body moulds, and the same is to even a greater extent true of the handle moulds, though these latter will be discussed more fully under another head.

The writer is a strong advocate of using natches of other material than plaster (clay or metal) in the sides of pressed moulds as well as in all handles, provided that—in the first case at least—the natches be sufficiently large that no trouble will be experienced in fitting the sides together.

Handle Moulds.

While this division includes all handle, knob, bow, and similar moulds, cup handles will be treated of particularly, since they form the largest part, observations relating to them being, as a rule, applicable to the other kinds also.

From a large number of sets, the life of cup handle moulds was found to vary between 60 and 80 dozen to the single mould, though in one or two cases, an even higher figure was reached.

The use of natches of other material than plaster has come into such general practice that it is unnecessary to insist upon their advantages, though there is still considerable doubt as what form of natch shall be used and of what material they shall be made. Glass, brass, or porcelain may be used, though in the opinion of the writer the last is far preferable if properly made. The body employed should be very hard when vitrified even though this qualification may entail slight brittleness, and the natches should be pressed from wet clay to secure maximum density. When dry, and before firing, the two parts should be fitted to each other by rubbing, but they should be fired separately, the hollows to a higher temperature than the humps. This will secure a fairly accurate fit. A mixture which has given good satisfaction consists of 60% feldspar and 40% China clay.

Greater accuracy in fitting will be obtained from dust-pressed natches, though those made by this method will be far softer and more easily worn than the others. Glass is better than porcelain so far as abrasion is concerned. Brass natches, frequently connected by a frame fitting around the outside of the handle moulds, are used to a considerable extent, and aside from their initial cost, which is heavy, are quite satisfactory.

In the case of large block handle moulds where the superfluous clay is forced into a richot or spare in the center of the handle itself, it will be found of advantage to place a hole in the center of this spare, thus allowing the

clay a means of escape. This relieves the pressure and enables the sides of the moulds to be brought closer together. The hole should be of sufficient size so that it will not get stopped up with clay.

Handle moulds made of clay and fired at ordinary biscuit heat have been used, and will wear far longer than plaster, though the writer has had but slight experience along that line. One or two such moulds gave fair satisfaction, although the ware did not deliver quite as readily as from plaster, owing, no doubt, to the moulds in question being insufficiently porous. The warping due to shrinkage is one of the serious difficulties connected with their manufacture; but by use of a suitable mixture, the shrinkage may be obviated and maximum porosity obtained. Such a body may be obtained by the use of 10 or 15% of strontium carbonate.

General Remarks on the Wearing Out of Moulds.

In the case of flat jiggered moulds the wear on the face is due first to the friction of throwing on bats, particularly when the moulds are still damp, and secondly to friction due to shrinkage in drying, this class of ware usually being allowed to dry completely on the moulds. The wear of inside moulds such as cups, bowls, etc., from which the ware is taken out soft, and where the slight shrinkage is away from the mould, is due to pressure, and this is also true of pressed moulds including handles. The solvent action of water which constitutes the chief part of casting slip is entirely responsible for the rapid destruction of moulds used in this process, pressure and friction being eliminated.

It is obvious, therefore, that in trying to preserve the moulds, two distinct remedial measures must be taken, one in the direction of giving greater resistance to friction, and the other looking to the formation of an insoluble plaster. Plaster may be rendered very hard by the addition of flour, dextrine, or other substances, but what few

experiments the writer has made along this line indicate that these tend to impair the indispensible quality of absorption.

An attempt was also made in the other direction—that of rendering the plaster insoluble—and this was done by the action of barium chloride. An insoluble film of barium sulphate formed over the surface, but it appeared soft, and was in fact a precipitate with no crystalline structure to give it the necessary stability. However, it would seem quite possible that an insoluble plaster might be prepared in some such manner.

NOTES ON THE PREHEATING TREATMENT OF CLAYS.

BY

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In the continuation of further work on the preheating of clays it was thought advisable to make an attempt to trace the effect of this treatment upon the structure of the clays. The results of this work are summarized in this paper, and additional information of some practical bearing is brought out.

The problem was attacked by the following methods:

1. Determination of the specific gravity of the dried and powdered clays.
2. Mechanical analyses of the normal and of the preheated clays.
3. Determination of the adsorbing power of normal and of preheated clays for malachite green solution.
4. Determination of the distribution of shrinkage and pore water.

Specific Gravity.

The results of the specific gravity determinations made on fourteen clays are given in table I. In this work it was found that although the determinations were made with the greatest care a certain irregularity was observed due to the great difficulty in obtaining uniform samples. There is probably no class of substances which shows such a great diversity in structure and composition as clays, and it was found that even in samples from the same lump, thoroughly kneaded and worked, decided differences in density were observed.

[1] By permission of the Director, U. S. Geological Survey.

TABLE I.
Specific Gravity of Clays.

No. Clay	Normal	150°	200°	250°	300°	350°	400°
1.....	2.451	2.456	2.630	2.603	2.603	2.657	2.621
2.....	2.537	2.548	2.636	2.612	2.609	2.644	2.647
3.....	2.577	2.591	2.600	2.600	2.590	2.593	2.590
4.....	2.596	2.589	2.646	2.629	2.629	2.664	2.664
5.....	2.560	2.560	2.550	2.605	2.600	2.600	2.600
6.....	2.510	2.512	2.562	2.545	2.556	2.580	2.573
7.....	2.510	2.490	2.648	2.638	2.627	2.653	2.665
8.....	2.603	2.621	2.653	2.650	2.655	2.692	2.696
9.....	2.784	2.741	2.728	2.725	2.721	2.747	2.751
10.....	2.476	2.560	2.605	2.639	2.638	2.637	2.644
11.....	2.575	2.587	2.649	2.650	2.645	2.676	2.697
12.....	2.680	2.707	2.709	2.729	2.769	2.732	2.696
13.....	2.768	2.739	2.701	2.761	2.820	2.825	2.773
14.....	2.645	2.666	2.684	2.712	2.662	2.743	2.708

However, taking into account this irregularity, all but one clay show a noticeable increase in specific gravity due to preheating, which must be ascribed to the expulsion of the small quantity of water held so persistently, and in part to a condensation in the volume of the clay. Since it is not likely that the crystalline matter has suffered any such change at the temperatures involved, we must conclude that the effect is confined to the non-granular clay substance. The contraction in volume might be explained by the closing up or shrinkage of the assumed colloidal matter, very similar to the contraction of the silicic acid gel and other materials of like character.

Mechanical Analysis.

In determining the changes brought about by preheating as regards the fineness of grain, four samples of clay were prepared by thoroughly mixing them and dividing each portion into two parts. One half was preheated and then put through the Schultz apparatus, the other was run through in the normal condition. The results are compiled in table II. In carrying out this work it became at once evident that the preheated clays showed an extraor-

dinary tendency to form aggregate particles, in spite of the fact that they were first mechanically shaken in water and apparently deflocculated by the use of NaOH and $Na_2C_2O_4$ solutions. These particles were found to be so hard that they could not be worked through the sieves by simple rubbing. The results show that for this reason the clays have become decidedly coarser, the surface factor has been decreased. This applies not only to the sieve sizes but also to the sizes separated by the first two cans. The difference between the normal and the preheated clays, therefore, is due to coagulation, the material has become "set," to use the language of the colloid investigators, and irreversible as far as practical purposes are concerned.

TABLE II.
MECHANICAL ANALYSIS.
Normal and Preheated Clays.

CLAY		Left on Sieves, Mesh					CANS			Overflow
		40	60	80	100	120	1	2	3	
G	N	0.84%	1.77%	1.33%	3.78%	0.20%	8.02%	15.12%	2.21%	66.72%
	300°	4.04%	5.76%	2.42%	7.08%	0.39%	16.90%	16.28%	3.00%	44.13%
A	N	1.96%	1.80%	1.50%	3.37%	0.16%	4.07%	4.45%	2.32%	80.37%
	300°	4.56%	2.66%	1.96%	1.33%	0.22%	5.47%	8.38%	5.01%	70.40%
S	N	1.11%	1.37%	0.58%	0.70%	0.15%	2.79%	26.56%	5.07%	61.66%
	300°	9.54%	9.28%	3.26%	2.20%	5.10%	5.74%	37.25%	4.39%	28.23%
H	N	0.30%	0.40%	0.34%	0.50%	0.08%	0.83%	3.84%	6.18%	87.52%
	300°	3.71%	2.77%	0.71%	1.99%	0.33%	3.29%	5.57%	4.44%	77.17%

(G) Alluvial clay, Groveport, Ohio. (A) Impure No. 2 fire clay, Athens, Ohio. (S) Joint clay, Urbana, Illinois. (H) Glacial clay, Heron Lake, Minn.

Malachite Green Adsorption.

Determinations were made on five samples in the normal and preheated condition. The work was done by Mr. H. E. Ashley. One gram of clay was thoroughly shaken in 100 cc. of malachite green solution, three grams per liter, and the amount of dye remaining in solution determined by the colorimetric method. The results of these tests are

presented in table III, and the values express the relative the adsorption of malachite green by the Tennessee No. 3 ball clay. Thus, the adsorption of the ball clay would be represented by 100. A clay giving the value of 300 would show three times the colloidal content of the standard material.

TABLE III.

CLAY	Extremely sticky Surface Clay, Albert Lea, Minn.	Joint Clay Urbana Illinois	Joint Clay, Peoria, Illinois	Alluvial Clay, Groveport, Ohio	Impure No. 2 Fire Clay, Athens, Ohio
Normal	600	142	175	104	160
Preheated at 250° C.	475	137	150	106	140

A glance at these figures shows that, although in four out of the five cases the adsorption has been decreased, the difference is not proportional to the difference in the physical behavior of the clays. It is evident therefore that, excepting the Minnesota clay, no decided change in the structure is indicated by this test. It would seem then that the "set" gel has about the same adsorption as the "reversible" gel. Hence, the adsorption of malachite green from its solution does not appear to be any measure of plasticity as far as these clays are concerned.

In making up preheated clays with water, it was observed that some heat was given off. It was thought to be interesting to determine approximately the amount of this heat and at the same time to compare it with the heat evolved by the same clay dried at 105°C. Thus, a sample of red surface clay was divided into two parts. One was dried at 105°, the other was preheated at 300°C. By placing the weighed amounts of clay into a copper receptacle covered with felt, adding a known amount of water and noting the temperature rise by means of a delicate thermometer, it was found, after making the necessary calcula-

tions and corrections, that the clay dried at 105°C, gave off practically four gram calories and the preheated clay five calories per gram.

Distribution of Shrinkage and Pore Water.

It was observed in the course of the experiments that the ratio of shrinkage to pore water in the various preheated clays did not remain constant. The amount of pore water increased at the expense of the shrinkage water. However, as the total water of plasticity does not decrease proportionally to the decrease in volume shrinkage, this difference is emphasized more strongly. This is illustrated by the results calculated for four clays. In these calculations the water of plasticity as well as the shrinkage and pore water are expressed in terms of the true clay volume. Thus the shrinkage water was calculated from the relation:

$$\% \text{ volume of shrinkage water} = \frac{d(v_1 - v_2)}{w} 100,$$

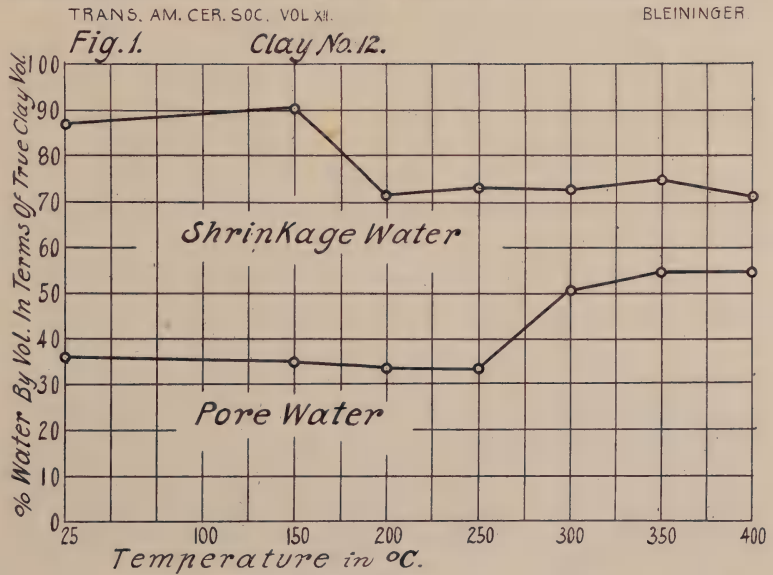
where v_1 = volume of wet brickette,
v_2 = volume of dry brickette,
w = weight of dry brickette.
d = specific gravity of the dried and powdered clay.

In expressing the volumes in terms of the real clay volume, they become more comparable.

TABLE IV.

CLAY		% by volume in terms of true clay volume						
		Normal	150°C	200°C	250°C	300°C	350°C	400°C
Alluvial Clay, Groveport, Ohio. Clay No. 12	Total water	87.20	80.52	71.11	73.00	72.60	74.60	70.80
	Shrinkage water..	51.09	45.49	37.61	39.22	21.70	19.66	15.98
	Pore water	36.11	35.03	33.50	33.78	50.90	54.94	54.82
Glacial Surface Clay, Heron Lake, Minn. Clay No. 13	Total water	95.20	90.00	92.60	90.70	84.30	97.10	84.40
	Shrinkage water..	42.65	41.80	38.92	35.37	28.27	31.17	20.35
	Pore water	52.55	48.20	53.68	55.33	56.03	65.93	64.05
Impure No. 2 Fire Clay, Athens, Ohio. Clay No. 14	Total water	72.19	78.06	73.17	70.33	75.78	71.60	71.88
	Shrinkage water..	49.05	47.55	47.43	43.23	41.06	38.96	33.34
	Pore water	23.14	30.51	25.74	27.10	33.82	32.64	38.54

The results are compiled in table IV. They are presented graphically in Figs. 1, 2 and 3. Referring to Fig. 1,

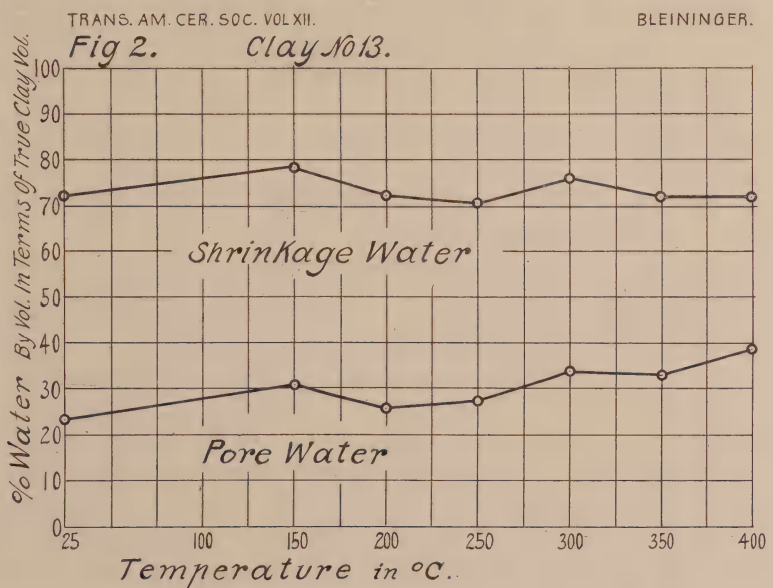


it is observed that with this clay, an alluvial surface clay, a marked increase in the amount of pore water is shown between 250 and 300°, and it is quite evident that the clay approaches the condition of an inert material. The two curves must meet at some higher temperature when the clay will have lost its plasticity. This increase in pore space brings out the interesting fact that the preheated clay will result in more porous ware after drying. From this it follows that it is entirely possible to preheat a clay to excess, not only as regards the working quality but also with respect to the resulting high porosity. In burning, the pore space is closed up more or less according to the degree of vitrification. In completely vitrified products the burning shrinkage is thus bound to approach the volume of the pore space in the dry ware. Preheated clays in some cases, therefore, would show an excessive burning shrinkage, which would put a more or less severe strain upon the structure and might cause cracking or checking. It is hence important to carry on the preheating treatment at as low a temperature as will overcome the drying difficulty or the undesirable stickiness which the clay may possess. From the work done along these lines it is evident that clays differ widely as to their increase in pore water on preheating. In some this increase is gradual and in others abrupt, resulting at a certain temperature in excessive porosity. The safest clays would probably be those for which the shrinkage-temperature curve shows the most gradual slope.

This leads to the question of the amount of water used in making up the clay. Naturally the more water is used the greater is the shrinkage bound to be as well as the final porosity in the dry state. If now a preheated clay is made up to the consistency of the so-called "slop" mold bricks with a large amount of water, the question arises whether or not the permissible limit of pore water might not be reached, so that, owing to the greater distance between the particles, the cohesive force would not suffice to hold the

mass together. This point was studied by taking two surface clays preheated to 250° C., which proved to work satisfactorily in the stiff plastic condition, and making them up in the regular wooden slop mold to the most suitable consistency. It was found that the bricks showed a tendency to "slump," indicating that the cohesion of the clays in this state was not sufficient to hold them up. They also cracked in drying, since they did not possess sufficient strength to withstand the strains caused by the larger drying shrinkage coincident with the large amount of water. On the other hand, the same clays behaved well in being made up by the dry-press process.

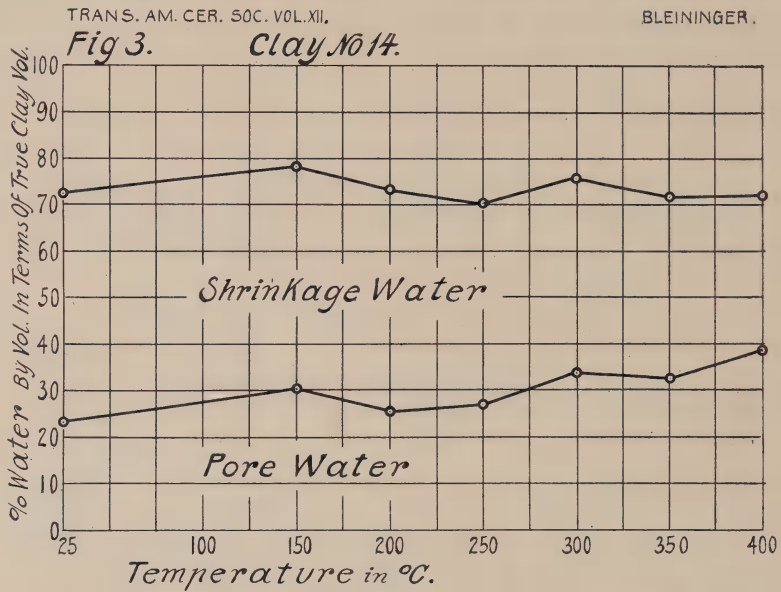
The clay represented by Fig. 2, an impure No. 2 fire



clay, of excessive plasticity, showed likewise a constant increase in the amount of pore water, but the change appears to be gradual. This may possibly be due to the more homogeneous character of this material. The shrinkage water retained by this clay at 400° still constitutes a large amount of the total water, thus indicating that the

residual plasticity is still considerable. This clay should be a safe material for preheating purposes.

In Fig. 3, the material is a surface clay of glacial



origin, and shows a sudden decreased in shrinkage water between 300-350° C., and a low amount of shrinkage water at the highest temperature. For the best results the preheating temperature in this case should not exceed 300°C.

From these illustrations it appears that the proper preheating temperature varies for different clays, and that it is important to carry on this drying at a temperature below the critical point indicated with some materials by a sudden decrease in the shrinkage water. This caution is not due to any possible difficulty in drying but to the danger of cracking in burning. A friend of the writer, on carrying on preheating tests on a large scale, found it necessary to carry the temperature up to 400° C. when he overcame the working difficulty of the material successfully. This shows the great variations in the behavior of different clays.

Drying Tests.

Six excessively plastic clays, preheated to 250° C., were made up to stiff clay consistency and pressed on a full size auger machine through a dry die into cylinders 3½ inches in diameter which were cut into discs 1½ inches thick. It was found that two of the clays worked better than in the normal state while four proved to be weaker and showed the need of lubrication, which it was impossilble to provide. It was evident that they were forced through the die under conditions of strain. However, no cracking took place in drying in spite of this and pronounced auger lamination. In burning the discs it was found that the loss due to cracking was fairly high, though close inspection seemed to indicate that lack of lubrication was responsible for the difficulty. It was also noticed that two of the preheated clays showed a noticeable increase in the tendency to efflorescence on the surface.

Conclusions.

1. Preheating seems to convert part of the plastic clay substance to the irreversible modification analogous to the "set" gels of colloidal chemistry. Such clays dry more easily, due principally to increased porosity.

2. The preheating should be carried on at as low a temperature as possible, only high enough to overcome the drying difficulty. High temperatures with some clays result in excessive pore space which may give rise to difficulties in burning due to cracking. It is quite likely that some clays cannot be preheated at all, owing to the short temperature range within which the change takes place. It is impossible to give general rules; each clay must be studied by itself. Temperature-shrinkage curves as used in this and the previous paper are helpful in indicating the behavior of a clay.

3. Most clays seem to require more careful lubrication in the preheated than in the normal state. The

amount of tempering water should be kept as low as possible.

4. There seems to be a tendency on the part of the preheated clay to release its soluble salts more easily than normal clay; this would indicate a greater tendency to show dryer efflorescence.

DISCUSSION.

Mr. Frink: Sewer pipe pops at 200° C. Will preheating overcome this?

Mr. Bleininger: No, I do not think so.

Mr. Lovejoy: Will preheating cause clays to laminate?

Mr. Bleininger: I do not think so.

Mr. Coulter: Does preheating increase fire shrinkage?

Mr. Bleininger: Yes.

Mr. Coulter: What stage?

Mr. Bleininger: During vitrification.

Mr. Ries: Will preheated clays return to the original condition if exposed to weather?

Mr. Bleininger: I do not know but it seems probable.

Mr. Ries: How long do you preheat the clays?

Mr. Bleininger: From 3 to 5 hours, according to the amount.

Mr. Yates: Did you work on raw or weathered clay?

Mr. Bleininger: All were raw surface clays.

Mr. Yates: The degree of granulation in clays depends to a considerable extent upon the amount of weathering. You can regulate drying troubles by mixing weathered and unweathered portions of the clay. Weathering increases the plasticity of the clay. In such a mixture, I would consider the unweathered portion as forming the body of the clay, and the weathered or plastic portion as the bond. Now if you have no body, and all bond, you will have drying troubles.

Mr. Staley: Is high surface tension due to colloids or adsorbed salts?

Mr. Bleininger: I do not know.

Mr. Lovejoy: If five hours is required to preheat a clay, do you consider this treatment practical?

Mr. Bleininger: Time is not necessarily a factor, except that necessarily consumed to get the heat through the clay.

Mr. Lovejoy: Will pre-grinding and use of a rotary dryer be necessary in order to lessen the time factor?

Mr. Bleininger: Regrinding would reduce the time required, and the rotary dryer appears to be the most suitable apparatus for the purpose.

Mr. Richardson: Have you experimented with a rotary dryer in this connection?

Mr. Bleininger: No.

Mr. Ries: Do all glacial clays behave in the preheating treatment as would weathered shale?

Mr. Bleininger: I do not know.

Mr. Ries: In the case of the unconsolidated surface clays, do you have to make any distinction between the portions at various depths from the surface?

Mr. Bleininger: Just below the tilled soil in some parts of Illinois there is a foot or two of clay that can be worked as it now is. Below this workable strata there is a joint clay that cannot be manufactured into bricks, and which would have to be preheated before using. I take this difference in working properties of this clay at the different depths as being due to freezing and thawing. This lower joint clay can be used if it is plowed and subjected to one winter's freezing and thawing.

Mr. Ries: Have you tested the tensile strength before and after heating?

Mr. Bleininger: No.

Mr. Plush: Bath tubs made from clay that has been delivered to the blungers in a frozen condition will invar-

iably crack. If this clay is ground in a wet pan, the bath tub will not crack so badly.

Mr. Yates: If you suddenly thaw frozen clay, you disintegrate the particles and therefore get trouble in drying. To overcome this you will have to open up the body, as for instance by the use of grog.

EXTRACTS FROM INVESTIGATIONS MADE BY STUDENTS IN THE DEPARTMENT OF CERAMIC ENGINEERING, OHIO STATE UNIVERSITY.

ABSTRACTED AND EDITED BY

Ross C. Purdy, Columbus, Ohio.

CHROMIUM - TIN - PINKS.

BY

A. S. Rea.

The work pursued in this thesis was a continuation of the investigation by Purdy and Brown on Chromium Tin Pinks.[1] The object of *their* experiments was to determine the permissible variation in composition of the stains, and also to determine the effects produced by adding chromium in the three forms.

1. Chromic Oxide ..... Cr_2O_3
2. Lead Chromate ..... $PbCrO_4$
3. Potassium Dichromate ..... $K_2Cr_2O_7$

None of the stains used by them were washed free of the soluble material. Inasmuch as it was not known whether the soluble salts affected the color or were injurious ,it was determined to wash and recalcine these same stains. The object of this thesis was, therefore,

(1) To determine the percent loss on washing and recalcining the chrome-tin-pink stains used by Purdy and Brown.

(2) To determine the effect of this treatment on the resulting stain and glaze colors.

It was not considered necessary to employ their entire series, 180 stains, to demonstrate the effect of washing and

[1] Trans. Am. Cer. Soc., Vol. XI, pp. 228-261.

recalcination, so it was decided to select only every other one or the even numbers only, making a total of 90 stains to be treated.

The following table gives the molecular compositions and the numbers of the stains used:

Table of numbers of the stains having equivalent content of Cr_2O_3 and CaO, as shown:

Equivalent of Cr_2O_3	Equivalents of CaO					
	3 0	2·5	2 0	1 5	1 0	0 5
.005	2	12	22	32	42	52
.02	4	14	24	34	44	54
.05	6	16	26	36	46	56
.10	8	18	28	38	48	58
.15	10	20	30	40	50	60

Constituents common to all stains.

1 Equiv. SnO_2

1 Equiv. SiO_2

Group A. Cr_2O_3 introduced as chromic oxide.

Group B. Cr_2O_3 introduced as lead chromate.

Group C. Cr_2O_3 introduced as potassium - dichromate.

Method of Procedure.

Fifty grams of each stain were weighed out very accurately and placed in an Erlenmeyer flask of 450 c. c. capacity. The flasks were placed on a table constructed for the purpose. Bottles of about 500 c. c. capacity were arranged beneath the flasks for the purpose of receiving the decanted liquid. Distilled water, which was used throughout the washing process, was conveyed to the flasks through a rubber tube connected to the distilled water faucet.

The flasks were filled up with water and thoroughly agitated for a time, after which the stains were allowed to settle. The supernatant liquid in each flask was then

siphoned off through a glass tube into the corresponding bottle below. The liquid from the first three washings was preserved for future analysis. In order to make it possible for the bottles to hold the first three washings, it was necessary to reduce the volume of the liquids by evaporation on a hot plate. In this way concentrated solutions were obtained. The liquid from the other washings was not preserved. The total number of washings for each group was as follows:

Group A. Chromic Oxide .....11 washings
Group B. Lead Chromate .....10 washings
Group C. Potassium Dichromate .....12 washings

Groups A and C were given additional washings because some of the stains of these groups still had a decided tint after the tenth washing, showing that all the soluble matter had not been removed. The stains of Group B were almost clear after the fifth washing. Lead chromate is itself very insoluble, and hence an excess would not impart such a deep yellowish tint to the liquid as is the case with potassium dichromate.

After the final washing, the stains were transferred to small evaporating dishes and evaporated to dryness on a hot plate. After cooling, the stains were then weighed and the percent loss calculated. The figures obtained were somewhat erratic, due to the fact that the drying conditions were not perfect. For this reason, the figures are omitted. The stains were then transferred to small Hessian crucibles and calcined in a Caulkins "Revelation" gas kiln to Cone 4, the length of burn being 12 hours. The stains were again weighed after calcining and the total loss figured.

The glaze used and method of compounding were same as described by Purdy and Brown.

Four burns of the glaze series were made as follows:

1st Burn	Cone 2 flat	28 hours	Cooled slowly.
2nd Burn	Cone 2 flat	26 hours	Cooled rapidly.
3rd Burn	Cone 1 flat	26 hours	Cooled slowly.
4th Burn	Cone 1 flat	20 hours	Cooled rapidly.

Coke was used as fuel.

Observations Made.

Behavior in the Washing Process. One of the first phenomena to be observed was the marked difference in volume alteration of the stains when treated with water in the washing process. Those high in lime and low in chromium became particularly light and voluminous, while those high in chromium, irrespective of the calcium content, settled down solidly with no apparent alteration in volume.

The following table gives the relative volume of the stains as they existed in the flasks after the addition of water:

No.	A	B	C
2	L		L
4	L	L	L
6	L	L	L
8	L	M	M
10	M	D	D
12	D	L	L
14	L	L	L
16	L	M	M
18	M	D	M
20	M	D	D
22	D	L	L
24	L	L	L
26	L	M	M
28	M	M	M
30	M	D	D
32	D	L	L
34	L	L	L
36	M	M	M
38	D	D	D
40	D	D	D
42	M	L	M
44	M	M	M
46	D	D	D
48	D	D	D
50	D	D	D
52	D	D	D
54	D	D	D
56	D	D	D
58	D	D	D
60	D	D	D

L = Light and voluminous.
M = Medium.
D = Dense and compact.

In general those high in calcium and low in chromium were the most voluminous. For example, the following numbers in all the groups showed excessive swelling:

Nos. 2, 4, 6, 12, 14, 22, 24, 32.

Those stains with high and medium calcium and high chromium were the most compact. In fact, in the latter cases, the stains formed such a solid cake that the supernatant liquid could be poured off directly without breaking up the residue. In some cases it was necessary to break up the cake with a spatula prior to subsequent washings. This was true with the following numbers in all the groups:

Nos. 20, 28, 30, 38, 44.

In those lowest in calcium and low in chromium the stain settled to a compact mass, while those low in calcium and high in chromium, although not swollen appreciably, did not form as dense a cake as those higher in calcium with the same equivalent of chromium.

On settling, many of the stains had a white or pinkish deposit settled onto the denser settled portion; those of lowest calcium, irrespective of the chromium content, having the heaviest deposit; those of highest calcium having the barest trace. This light in soluble matter, which settled very slowly, would cause the liquid to remain cloudy or milky for a considerable length of time after the addition of water to the stains.

The following were the slowest to clear up, due to this cause:

A	B	C
38	46	40
40	48	46
48	52	48
50	54	50
52	56	54
54	58	56
56	60	58
58	..	60
60	..	..

Color of the Decanted Water. In Groups A and C (chromic oxide and potassium bichromate), the first decanted water from those lowest in chromium was almost colorless, there being only a slight yellowish tint, while in each succeeding number, with an increase of chromium, the color increased in tint until those highest in chromium had a strong tea or straw color. The strength of color also varied with the calcium content, those of low calcium being of a slightly deeper tint than those of high calcium. The color of Group C was slightly stronger than in Group A. In Group B (lead chromate), the decanted water from all the stains was almost colorless. There was a slight tint in Series 42-50 and 52-60, there being a progressive increase from none in Series 42 and 52 to a slight yellow in Series 50 and 60.

On evaporating the liquid from the first two washings, a scum was noticed to form on most of the solutions soon after they became thoroughly heated, and this increased as the solutions became more concentrated. The following table gives the relative degree of scumming for the three groups:

2 M	12 M	22 S	32 M	42 S	52 N
4 M	14 M	24 T	34 M	44 S	54 N
6 T	16 T	26 T	36 M	46 M	56 N
8 T	18 T	28 S	38 N	48 N	58 N
10 M	20 S	30 S	40 N	50 N	60 N

T = Thick scum.
M = Medium scum.
S = Slight scum.
N = No scum.

In general those high in chromium and low in calcium showed the least, while those high in calcium and low in chromium showed the greatest tendency to scum.

After the tenth washing, the color of the supernatant liquid on all the stains was very weak. All of those of Group B were clear, while a few members of both Groups A and C, highest in chromium, still had an appreciable

tint. Those of Group C still had a slightly stronger color than those of Group A.

It was found that those lowest in lime were the easiest to wash free of color, i. e., while Series 52-60 had the strongest color in the beginning, at the end of the tenth washing they had a much weaker tint than the others.

Loss Due to Extraction of Soluble Salts. The results of the determination of the soluble matter are somewhat erratic. A number of causes may be given as partially responsible for this. One of the possibilities of error was the tendency of the light, unconsolidated stains to be carried over when siphoning off the supernatant liquid. However, the loss from this cause was probably very slight, as extra precaution was observed in such cases.

Another, and perhaps the most important source of discrepancy was the fact that the stains are more or less hydroscopic and no doubt took up moisture from the air. Also, it was not possible, with the limited time and facilities, to dry all the stains in desiccators before each weighing, or to carry on the determination with the accuracy and precision that a chemical analysis requires.

However, from the figures obtained, general conclusions can be drawn which are of greater importance than the exact figures for any particular stain.

In all the series, those high in calcium showed the greatest losses; those low in calcium, very small losses. Also, in general, those low in chromium showed a greater loss than those high in chromium, indicating that the chromium represents a minor portion of the loss.

No.	Pecentage Total Loss			Equivalent Content of	
	A	B	C	CaO	Cr_2O_3
2	11.2	7.6	10.8	3.0	0.005
4	11.5	9.5	9.6	3.0	0.02
6	11.1	6.8	9.0	3.0	0.05
8	10.1	6.8	9.0	3.0	0.10
10	8.9	9.0	10.3	3.0	0.15
12	8.7	4.4	8.1	2.5	0.005
14	8.7	8.1	8.4	2.5	0.02
16	7.9	4.7	6.6	2.5	0.05
18	8.0	6.5	6.9	2.5	0.10
20	7.2	5.8	6.7	2.5	0.15
22	6.8	4.6	6.9	2.0	0.005
24	6.3	6.7	6.3	2.0	0.02
26	5.8	4.6	5.5	2.0	0.05
28	6.2	6.3	9.0	2.0	0.10
30	5.5	7.9	8.4	2.0	0.15
32	5.4	5.7	5.1	1.5	0.005
34	5.4	4.7	4.4	1.5	0.02
36	5.2	4.3	3.5	1.5	0.05
38	4.5	5.5	6.8	1.5	0.10
40	2.8	6.7	8.2	1.5	0.15
42	2.9	4.2	2.4	1.0	0.005
44	2.4	3.6	2.4	1.0	0.02
46	2.4	4.0	1.6	1.0	0.05
48	1.5	4.8	5.2	1.0	0.10
50	1.4	5.0	6.3	1.0	0.15
52	1.6	2.5	2.2	0.5	0.005
54	1.3	2.8	1.7	0.5	0.02
56	1.2	3.9	1.4	0.5	0.05
58	1.2	5.7	1.3	0.5	0.10
60	1.2	5.2	2.0	0.5	0.15

Tints Obtained in the Glazes.

It was in the glazes that the most pronounced change in color, due to washing and recalcination, was produced. In some there was little, if any, change, while in others there was considerable. In some cases, greens, browns, and lilacs were changed to pinks and reds by simply washing and recalcining the stains. The comparison of colors before and after washing are given below:

COLORS DEVELOPED IN GLAZES.

Group A (Chromic Oxide).

Eqv. CaO in Stains	3.0	2.5	2.0	1.5	1.0	0.5	Eqv. Cr_2O_3 in Stains
Before	2 Pink	12 Pink	22 Lilac Pink	32 Lilac Pink	42 Lilac Pink	52 Lilac Pink	0.005
After	"	"					
Before	4 Red	14 Brownish Red Purplish Pink	24 Lilac Red	34 Lilac Lilac-Pink	44 Lilac Good Red	54 Lilac Red	0.02
After	"						
Before	6 Brown Red	16 Brown	26 Green Red	36 Green Red	46 Green Brown. Red	56 Green Red	0 05
After	"	"					
Before	8 Green	18 Green Brownish Red	28 Green Brown. Red	38 Green Brown-Red	48 Green Brown. Red	58 Green Brown. Red	0 10
After	"						
Before	10 Green	20 Green Brownish Red	30 Green Brown. Red	40 Green Brown. Red.	50 Green Brown. Red	60 Green Brown Red	0.15
After	"						

COLORS DEVELOPED IN GLAZES.

Group B (Lead Chromate).

Eqv. CaO in Stains	3.0	2.5	2.0	1.5	1.0	0.5	Eqv. Cr_2O_3 in Stains
Before	2	12	22	32	42	52	0.005
After	Pink "	Pink "	Pink "	Lilac Pink	Lilac Pink	Lilac Pink	
Before	4	14	24	34	44	54	0.02
After	Pink "	Pink "	Pink "	Lilac Pink	Lilac Pink	Lilac Pink	
Before	6	16	26	36	46	56	0.05
After	Red Red Good	Red Red Good	Lilac Red Good	Lilac Red Good	Lilac Red	Lilac Red	
Before	8	18	28	38	48	58	0.10
After	Red "	Red "	Lilac Red	Lilac Red	Elephant's Breath Brown. Red	E Breath Brown. Red	
Before	10	20	30	40	50	60	0.15
After	Red Brown. Red	Red "	Lilac Red	Lilac Brown, Red	E. Breath Brown. Red	E. Breath Brown. Red	

COLORS DEVELOPED IN GLAZES.

Group C (Pot. Dichromate).

Eqv. CaO in Stains	3.0	2.5	2.0	1.5	1.0	0.5	Eqv. Cr_2O_3 in Stains
Before	2 Pink	12 Pink	22 Pink	32 Pink	42 Red	52 Red	0.005
After	"	"	"	"	Pink	Pink	
Before	4 Red	14 Red	24 Red	34 Red	44 Red	54 Red	0.02
After	Red Good	Red Good	Red Good	Red Good	Red Good	Red Good	
Before	6 Brown	16 Brown. Red	26 Red	36 Red	46 Brown. Red	56 Red	0.05
After	Red Good	Red Good	Red Good	Red Good	Red Good		
Before	8 Brown	18 Brown	28 Brown. Red	38 Brown. Red	48 Brown. Red	58 Green	0.10
After	Brown. Red	Brown. Red	" "	" "	" "	"	
Before	10 Green	20 Green	30 Brown. Red	40 Brown. Red	50 Brown. Red	60 Green	0 15
After	Brown. Red	Brown. Red	" "	" "	" "	"	

It is seen by comparing the colors as shown in chart that the most marked changes in tint were in the high chromium end of the groups, being more pronounced where the calcium is low in Groups A and B, and where the calcium is high in Group C.

Effect of Source of Chromium: The general terms used in above tables do not indicate the differences in tint produced by use of the different chromium compounds. With low chromium (0.005 and 0.02 eqv. in stain) there are no marked differences. With more than 0.02 eqv., however, there is a decided difference in the tints.

DISCUSSION.

Mr. Binns: Do I understand that each trial was identically the same as the others except as to the source of the chromium?

Mr. Purdy: Yes, as plotted in the paper and shown on the mounted cards the chromium increases from top to bottom and the whiting from left to right.

Mr. Frink: How do you account for that difference? Have you any theory that will explain that?

Mr. Purdy: No sir, that is one thing we avoided doing. Dr. Mellor says that we did not have complete action, we only had arrested re-action. I do not know what he means by the distinction between the arrested and the completed re-action as applied to such calcines as chrome tin pink stains.

RANGE IN COMPOSITION OF AN ENGOBE AND GLAZE FOR A GIVEN BODY.

BY

GEO. P. FACKT.

The body clay used was a buff burning clay from

Progress Brick Co., St. Louis, Mo. Rational analysis of this clay gave

Sol. in hot H_2SO_4	72.51
Feldspathic material	4.12
Quartz	23.37

Engobes were applied on stiff-mud bricks just after manufacture, i. e., before drying.

The first series of engobes were designed to show effect of various clays in the following type formula:

Clay	50
Flint	30
Feldspar	20

Each member of this series contained only one clay. The engobes were applied by dipping.

The clays that gave the best results were Georgia Kaolin (Macon), Dillsboro Kaolin, and English Ball Clay No. 7.

The condition of body and manner of application of these engobes were similar to those described by Geijsbeek. Results in this instance check Geijsbeek contention that with the same formula each change in clays, other constituents remaining constant, produces a change in character of results.

The second series of engobes had type formula as follows:

Clay	65
Flint	25
Feldspar	10

This series was designed to demonstrate the best proportion of

Dillsboro Kaolin	Mayfield Ball
Georgia Kaolin	Mayfield Ball
Georgia Kaolin	Mayfield Ball
Dillsboro Kaolin	Tennessee Ball No. 1
Georgia Kaolin	Tennessee Ball No. 1
Mayfield Ball	Tennessee Ball No. 1

None of these engobes proved to be satisfactory on account of not being sufficiently vitrified and not adhering to the body.

Evidence concerning effect of variation in kind of clay used checked that obtained from Series I.

The third series was designed to ascertain the best ratio of feldspar and flint in engobes containing 65% clay.

Without waiting for results from Series III, two other series were designed in which the ratio of flint to feldspar was kept at ratios of 4:3 and 3:4 respectively; varying the percentage of clay (kaolins) from 50 to 80.

Not one of the engobes in Series II, III or V proved to be successful, owing to combination of clays tried. Great difference in effect produced by the different clays was noted. Three more series were devised to determine the best proportion and mixture of clays. The following gave the best results:

Engobe No.	62	63	72	73	94	82
English Ball Clay No. 12	30	40	30	35	40	20
Dillsboro Kaolin	17.5	12.5	15	17.5	20	20
Georgia Kaolin (Macon)	17.5	12.5	15	17.5	20	20
Flint	20	20	24	18	12	24
Feldspar	15	15	16	12	8	16

Nos. 62 and 72 were the best in all respects. Heat treatment of the burns ranged from Cone 4 to Cone 6 in 30 hours.

The Glazes.

The glazes tried are shown in the following table. They were of the usual raw lead type, using white lead.

Eqv. Al_2O_3	Equivalent SiO_2				
0.25	(a) 1.75	(a) 1.975	(a) 2.2	2.425	2.65
0.30	(a) 1.85	(a) 2.075	(a) 2.3	2.525	2.75
0.35	(a) 1.95	(a) 2.175	(a) 2.4	2.625	2.85
0.40	(a) 2.05	(a) 2.275	(a) 2.5	2.725	2.95
0.45	(a) 2.15	(a) 2.375	(a) 2.6	2.825	3.05
0.50	(b) 2.25	(b) 2.475	(b) 2.7	2.925	3.15

$$\text{RO common to all} \begin{cases} 0.4\ PbO \\ 0.2\ K_2O \\ 0.2\ CaO \\ 0.2\ ZnO \end{cases}$$

Glazes marked *a* were excellent glazes for the purpose at hand. They were matured nicely at Cone 6; not overburned or dimmed.

Glazes marked *b* were tending towards matts.

MATT GLAZE AT CONE 7-8.

BY

W. P. EARLE.

$$\left.\begin{matrix} 0.15\ K_2O \\ 0.33\ PbO \\ 0.52\ CaO \end{matrix}\right\} \quad 0.45\ Al_2O_3 \quad \begin{cases} 1.4\ SiO_2 \\ 0.1\ SnO_2 \end{cases}$$

$$.09\ CuO$$
$$.05\ Fe_2O_3$$

PRODUCTION OF FLEMISH WARE.

BY

S. P. WARD.

Object.

The object of these experiments was to produce a blue-gray stoneware, soft in color, with raised decorations in deep blue. The body was to be impervious to water.

The Body.

The blue gray body was readily obtained by adding 10% feldspar to a stoneware clay, and burning with such intensity of heat treatment as to obtain deep blue-stoning (Cone 8).

It was found that to obtain the blue tint desired, 0.0625% cobalt oxide (introduced as a component of a stain) had to be added to the body.

The Relief Decorations.

To obtain bright glossy blue relief decorations, cobalt

was added to various types of glazes in varying proportions. The prime requisite was that the glazes should be perfect and the color a characteristic cobalt blue, after subjection to strong salt glazing treatment.

From the several series tried, the following glaze was taken as having best withstood the salt glazing treatment at Cone 4:

$$\left.\begin{matrix} 0.5\ PbO \\ 0.2\ K_2O \\ 0.2\ CaO \\ 0.1\ ZnO \end{matrix}\right\} \left\{\begin{matrix} 0.3\ Al_2O_3 \\ 0.05\ Co_3O_4 \end{matrix}\right\} 1.9\ SiO_2$$

Attempts were made to imitate the salt glaze effect by using glazes of the porcelain and bristol type. The experiments tried were not successful.

DISCUSSION.

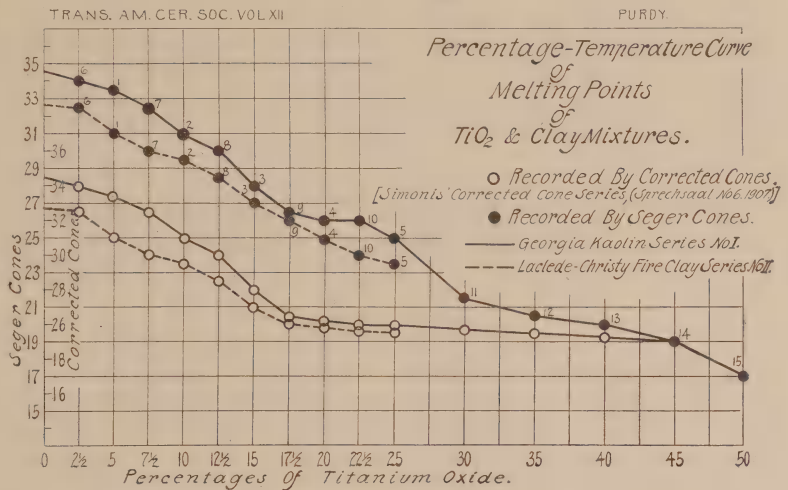
Mr. Binns: There is one point not quite clear to me. Do I understand that the blue color was not in the form of fusible glaze?

Mr. Purdy: Yes, the color was introduced in the glaze and painted on the relief decorations.

EFFECT OF TiO_2 ON POINT OF DEFORMATION OF CLAY.

BY

CHALMER BRYCE.


TRANS. AM. CER. SOC. VOL XII
PURDY.
Percentage-Temperature Curve of Melting Points of TiO2 & Clay Mixtures.
Recorded By Corrected Cones. [Simonis' Corrected Cone Series, (Sprechsaal No6. 1907)]
Recorded By Seger Cones.
Georgia Kaolin Series No I.
Lacleade-Christy Fire Clay Series No II.
Seger Cones
Corrected Cones
Percentages of Titanium Oxide.

COLOR SERIES FOR MATT GLAZES AT CONE 2-4.

BY

MILLARD F. GIBSON.

The glaze used was

$$\left.\begin{matrix} 0.15\ K_2O \\ 0.10\ PbO \\ 0.10\ ZnO \\ 0.35\ CaO \\ 0.30\ BaO \end{matrix}\right\} \quad 0.27\ Al_2O_3 \quad \left\{ 1.9\ SiO_2 \right.$$

The experiments did not progress beyond obtaining suitable base matt glaze and determining the equivalent quantity of the several oxides necessary to produce desired tins.

Following are the limits (in equivalents) of content of the coloring oxides:

Coloring Oxide	Raw Lead Glazes (Bright) by Purdy		Matt Glazes by Gibson			
	Commercial Limits in Equivalents		Commercial Limits in Equivalents		Possible Limits in Equivalents	
CuO	0.05	0.125	0.03	0.15	0.005	0.18
CoO	0.002	0.06	0.002	0.08	0.001	0.10
MnO_2	0.03	0.15	0.02	0.20	0.01	0.25
Fe_2O_3	0.01	0.05	0.01	0.05	0.005	0.10
Cr_2O_3	0.01	0.05	.....	....	.....	....
NiO_2	0.01	0.05	0.01	0.10	0.01	0.10
Ur_2O_3	0.002	0.008	0.002	0.009	0.002	0.01

SUBSTITUTION OF DOLOMITE FOR WHITING IN CERAMIC BODY AND GLAZES.

BY

ARTHUR F. KING.

Two samples of dolomite were used:

No. 1 from Moore Bros., Springfield, Ohio.

No. 3 The Woodville White Lime Co., Woodville, Ohio.

Dolomite	No. 1	No. 2
SiO_2	1.35	0.61
Al_2O_3	0.67	0.63
Fe_2O_3	0.20	0.09
$CaCO_3$	53.44	52.37
$MgCO_3$	43.86	46.08

Dolomite in Body.

Substitution of dolomite for whiting was made in the following bodies:

	Body No. 1	Body No. 2
Brandywine Feldspar	25	25.8
Whiting	7	3.7
Florida Kaolin	40	41.4
Golding's Flint	28	29.1

For comparison bodies were made on these formulae, using in one a precipitated calcium carbonate secured from The International Chemical Co., Camden, N. J.; and in the other a Paris White from The Potters Supply Co., East Liverpool, Ohio.

Material	Body No.	Cone	Percent Porosity $\frac{W-D}{W-S}$	App. Sp. Gr. $\frac{D}{D-S}$	Percent Absorption $\frac{W-D}{D}$	Percent. Drying Sh'r'k.	Shrinkage Total
Ppt. Whiting	1	8	11.0	2.2	5.64	7	13.
Paris White	1	8	9.1	2.21	4.43	8	13.5
Dolomite No. 1.....	1	8	0.74	2.29	0.32	8	13.
Dolomite No. 2.....	1	8	0.77	2.29	0.33	4	12.
Ppt. Whiting	1	5	16.13	2.05	9.36	7	12.5
Paris White	1	5	24.2	2.11	13.54	7.5	12.5
Dolomite No. 1.....	1	5	3.39	2.36	1.48	8.0	13.0
Dolomite No. 2.....	1	5	3.57	2.32	1.56	5.0	12.5
Ppt. Whiting	2	8	9.6	2.28	4.60	7.5	13.0
Paris White	2	8	8.51	2.37	3.92	7.5	12.5
Dolomite No. 1.....	2	8	5.07	2.37	2.13	8.0	13.0
Dolomite No. 2.....	2	8	6.20	2.35	2.64	5.0	12.5
Ppt. Whiting	2	5	10.66	2.30	5.18	6.0	12.0
Paris White	2	5	11.64	2.37	5.43	6.5	12.0
Dolomite No. 1.....	2	5	3.86	2.36	1.60	6.5	13.0
Dolomite No. 2.....	2	5	5.66	2.38	2.52	6.0	13.5

Dolomite in Glaze.

Dolomite was substituted by weight for whiting in raw lead, raw matt and Bristol glazes.

No effect of this substitution was noted except in the matt glazes. In the matt glazes, the dolomite series gave no trouble from crawling, crackling or beading. With whiting, considerable difficulty was experienced in obtaining a perfect matt coating.

Dolomite can be secured for $6.00 per ton, ground to pass 150 mesh sieve.

It can be used in all bodies in which absolute freedom from iron tints is not a requisite.

MATT GLAZES.

BY

W. N. CLAFLIN.

The following are conclusions drawn from several glaze series. The glazes were burned to Cone 1 in 30 hours.

Good matts that worked well on porous biscuit tile applied without resorting to the use of any gum to insure freedom from flaking, were obtained within the limits here shown:

$$\left.\begin{matrix}0.45\text{-}0.45\ PbO\\0.00\text{-}0.15\ ZnO\\0.15\text{-}0.10\ K_2O\\0.40\text{-}0.30\ CaO\end{matrix}\right\}\ 0.34\ Al_2O_3\ \Big\}\ 1.616\text{-}1.313\ SiO_2$$

Influence of Al_2O_3. In the preliminary study on known matts, it was clear that the conclusion that mattness is largely dependent on the equivalent of Al_2O_3, or of clay, was erroneous. A rather high clay content is undoubtedly favorable to mattness, but matt glazes with low clay content have been reported. True, insoluble matt glazes only are considered here. Immatures glazes with matt texture may be produced by overloading with Al_2O_3, or with clay, but these are not stable, nor in most cases insoluble.

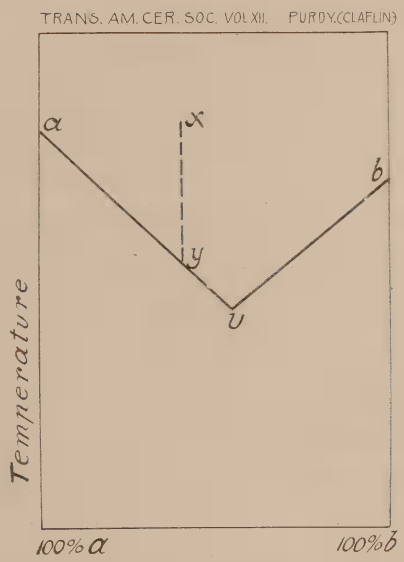
Influence of Oxygen Ratio. This seems also to be a rather uncertain factor. Professor Orton's curve[1] shows that an O. R. of 2.3 is necessary to obtain a matt at Cone 1. Bryan's matt maturing at Cone 02 to Cone 2 has an O. R. of 1 : 1.19. I obtained good matts with an oxygen ratio as low as 1 : : 1.13. Evidently the O. R. is not the entire governing factor in production of matt textures. Quite evidently also what Professor Orton had to say in this connec-

[1] Trans. Am. Cer. Soc., Vol. X. pp. 547-582.

tion is true only in glazes containing high equivalent of components like barium carbonate (0.3—0.4). His matts were not in all cases due to the same cause. Some were immature glazes, while a few were crystalline.

All matt glazes published by Binns and designed to mature at Cone 1, had oxygen ratio lower than that specified by Orton.

Influence of RO. Matt glazes do not have a characteristic RO. The make-up of the RO may be of a very variable character. In the case of one of the glazes, the substitution of 0.05 equivalent CaO for K_2O changed a bright



glaze to a good matt. "Overloading the RO" is often considered to be productive of mattness. It is not at all clear what is meant by "overloading of the RO." If it refers to use of an unusually large equivalent of some base, the experiment here made would indicate that matt texture is not always to be thus obtained.

The following theory seems plausible as to the cause

of mattness. The usual matt glaze, when burned, is considered to be a complicated solution of silicates, aluminates and oxides. It is not possible from empiric studies to determine the nature of the components existing in a fused glaze, but they are considered as forming (in the molten state) mutual solutions having components in excess, and from which, on solidification, the excess components crystallize out. Mattness is considered to be due to crystallization out of solution of one or more of the components, and a clear glaze is the result of solidification without the formation of crystals.

For simplicity, let us consider the glaze to be comprised only of two mutually soluble components. In the figure, "aub" represents the fusion curve of the soluble substances "a" and "b." The abscissae represent percents of "a" and "b," the ordinates temperatures. Starting with a fused solution of the components, at the temperature represented by "x," let us cool it down to "y." If the solution is perfectly fluid, allowing of free movement and circulation of the molecules, further cooling from "y" will result in the crystallization of "a." The constitution of the remaining solution varies along the line "yu." The point "u" is a eutectic point. At this point the whole mass will either crystallize or merely solidify in an amorphous condition. The mixture represented by the point "u" may be considered as the solvent, and the excess component "a" the solute. This process could not take place if the liquid becomes very viscous or solidifies before it reaches the saturation point of "a." Solidification and freezing are different things. Freezing is accompanied by the formation of crystals and takes place at a definite temperature. In the case of solidification, there is no definite transition point, but the change from solid to liquid extends over a considerable range of temperature. The mass gradates from a solid to a soft mass, to a viscous fluid, to a thin liquid. If in the above example the whole mass becomes viscous or solidifies before the point "y" is reached, the crystallization of "a" can take place only very slowly,

if at all. The mass remains in solution and a solid solution is the result.

The readiness with which the excess component will crystallize is also considerably of a factor. Not all components of a fused magma have the same speed of crystallization.

The size to which the crystal will grow is also a factor. This, to be sure, is controlled largely by the viscosity of the "mother" magma, and yet as seen in "Crystal Glaze" study by Purdy and Krehbiel, the crystallizing components did not grow to the same magnitude. Speed of crystallization may be effective in this.

A clear glaze then is a solid solution, that is, it attains a viscous or a solid state before the excess components could crystallize out.

A true matt glaze is one in which at least one of its components has crystallized out before the mass became too viscous.

Viscosity has an important function in glaze manufacture. To viscosity of the mass, when it reaches the point of supersaturation of the excess component, can be attributed the formation of all clear glasses. It interferes with the mobility of the molecules, and hence prevents crystallization in accordance with the laws of solutions.

It is apparent that comparatively high concentration of one of the components would be advantageous to mattness, because it would reach its saturation point much sooner and be crystallizing out over a longer temperature range. This, however, need not necessarily mean excess of any one of the oxides shown in molecular formula of the glaze.

There are no data published, nor is there any logical theoretical reasoning that supports Professor Binns' contention[1] that "the constitution of matt glazes consisted in the formation of aluminates in mutual solutions with the silicates." His statement may be correct for some glaze mixtures. It is not logical, however, to argue that all

[1] Trans., Am. Cer. Soc., Vol. X, p. 580.

true matt glazes are thus caused. It is quite logical, on the other hand, to argue that aluminates and silicates may mutually dissolve and form, when cooled, glossy glazes.

Mr. Stull[2] was, in the writer's opinion, quite right when he ascribed the cause for true mattness to crystallization, but quite in error when he inferred that spinels could not be formed at these lower temperatures as components of fused glazes.

Feldspar Content. Feldspar content of over 0.15 equivalent in the mixtures here tested tends to produce a gloss glaze. 0.15 to 0.10 equivalents of feldspar is advantageous to these matt glazes, since it makes the glaze sufficiently fluid to flow and heal. The glazes here tested were quite sensitive to chaneg in equivalent content of feldspar. When more than 0.15 equivalents were used, the glazes developed a gloss, and when less than 0.10 equivalents were used, the glazes cracked badly and did not again run smooth.

Thickness of Application. It has often been contended that matt glazes must be applied thickly. In fact, this is the general procedure in potteries. The matt glazes here developed, however, were not applied in thick coatings. They were applied only as thick as the ordinary glossy raw lead glazes (enamels) on tile. This procedure was purposely followed because of working on the theory of cause of mattness just outlined. A true matt glaze need not be applied thickly even on porous wall tile. This is contradictory to the statement made by Binns.[1]

Method of Application. These glazes were applied by dipping. No gum or sticky medium was used. That the use of a gum was not always necessary, has thus been proven.

DISCUSSION.

Mr. Binns: I would like to ask whether Mr. Purdy has any samples of these glazes here.

Mr. Purdy: I had them, but in the rush of starting I mislaid them.

Mr. Binns: I am sorry, because I could possibly have made some argument upon the appearance of each glaze itself. In other words, there are matt glazes and matt glazes. The matt glaze in my judgment is not simply a dull glaze, but a glaze which develops that peculiar silky or kid glove texture which is so pleasing to the touch. It is of course perfectly true that dull glazing can be developed in that way, but I have never found that peculiar silkiness. It does not excite the pleasurable feeling that a true matt glaze does.

I have done quite a good deal of work on matt glazes but I have never seen or come across any important variation from the rule which I have always followed, and that is if you prescribe a glaze with an oxygen ratio of one to one and a half or two to three, and if the basic content and the alumina and silica content are proportioned in the proper way, you will never fail to secure the matt glaze. The one exception to the rule is barium oxide. With that you have to change not necessarily the oxygen ratio but the alumina silica content. It has to come down considerably lower if any portion of barium exide is included in the glaze. That I attribute to other causes which might not come in here. The same formula without any change other than raising the oxygen ratio from one to two produces a bright glaze.

I do not want to dogmatize on the reasons for this, but I do not quite follow the reasoning of the writer of the paper. He says on the one hand spinels may be formed in the matt glaze and yet denies that these aluminates produce the matt. I do not quite see the consistency of that argument.

Mr. Purdy: Mr. Claflin's argument is this: You cannot say that since aluminates may be formed in glazes, that mattness is due to the formation of aluminates. I think he is logical in that.

We have produced matt glazes with very low alumina and in a few cases with practically no alumina, and I think Mr. Stull last year reported some matt glazes made

by him that had no alumina so far as the original constituents were concerned. The making of a bright glaze from a matt glaze by merely increasing the oxygen ratio is a possible way of making a good glaze, but the reverse of that is not a possible way of making a matt glaze in all instances.

Prof. Binns first experiment in matt glazes was made when developing a line of bright glazes. In his experiments he changed bright glazes over into matt glazes by decreasing the oxygen ratio; but in that instance he was working with most favorable Ro and R_2O_3 contents. Prof. Orton and also Mr. Rhead have reported in our transaction similar attempts to produce matts by decreasing oxygen ratio of bright glaze formulae, and each of these experimentors reported their attempts as failures.

Now the matt texture that Mr. Claflin describes is exactly the one described by Professor Binns. Our test is always on the soft part of the cheek. A perfect matt does not have to be a thick glaze in order to have a texture that will feel smooth on your cheek. Of course, if you are putting the glaze on a rough body you will have to have more glaze to fill in the depressions and make the surface smooth. Mr. Claflin's glazes flow well, as much as you would expect a matt glaze to flow, and had that nice soft texture.

Mr. Binns: In this connection I want to see the RO content of the glaze. Professor Purdy questions the possibility of making a matt glaze from a bright by simply reducing the oxygen ratio.

Mr. Purdy: In that case, no. I have done that myself. I have, however, failed more often that I have succeeded. Oxygen ratio is not the prime factor in production of matts.

Mr. Binns: I might say with the proviso that the fire must be adapted to the RO content, I have never failed to do it. I am speaking only within the limits of my own experience. I advanced this theory, and I think my paper

on matt glazes was the first one to open the ball. A matt glaze can be attributed to excess of lime. I believe that it is a commercial method of producing some of them, but the surface is never of silky texture. And other glazes have been produced by underfiring which, as the paper has pointed out, are true matts. It is certainly true that the matt glaze in itself is a result of some kind of crystallization or separation, if you prefer the word. I do not know that it is necessary that the excess components, either oxide or mineral, are bound to be separated in a crystal form. I have been challenged to show crystals in a matt glaze under the microscope, and I have not always succeeded in doing it. But then to show the crystal upon the surface on partially opaque glass is not always an easy thing. I still maintain that the main factor in the production of a matt glaze is a low oxygen ratio. I can produce matt glazes with other oxygen ratios but not invariably, while the ratio of 2 to 3 is in my experience invariable. The proper proviso being made that the RO must balance with the fire. If a phenomenon appears like that with unvarying regularity I do not quite see why it does not approach to something like a law.

THE LIMITS OF COMPOSITION OF ENAMELS FOR CAST IRON.

BY

MERRITT B. CHENEY.

(ABSTRACTED BY H. F. STALEY.)

Mr. Cheney quotes Von R. Vondracek, who gives the following as the allowable limits of composition for ground coats for cast iron, according to German practice:

$$\left.\begin{matrix} 0.3\text{-}1.0\ Na_2O \\ 0.0\text{-}0.7\ CaO \end{matrix}\right\} \begin{matrix} 0.0\text{-}2.0\ B_2O_3 \\ 2.6\text{-}6.3\ SiO_2 \end{matrix}$$

A fritt was made up of borax and boric acid in the proportion represented by the formula $Na_2O, 3\ B_2O_3$, or one equivalent each of borax and boric acid. One equivalent of this fritt was used in each of the experimental

coats. Additions of feldspar, one-tenth equivalent at a time, were made until one full equivalent of the spar was reached. To the pure fritt and to each of the fritt-feldspar mixtures, additions of clay of five-hundredths equivalents each were made until three-tenths equivalents had been reached.

Most of the seventy-seven trial coats were entirely too soft. Workable compositions were not reached with either feldspar or clay alone. Using the two together, the following limits of composition for a ground coat of this class were obtained:

$$\left.\begin{matrix} .40\text{-}.50\ K_2O \\ .50\text{-}.60\ Na_2O \end{matrix}\right\} .55 \text{ to } .63\ Al_2O_3 \left\{\begin{matrix} 1.5\text{-}2.0\ B_2O_3 \\ 2.75\text{-}3.25\ SiO_2 \end{matrix}\right.$$

As will be readily seen, these limits are narrow and probably do not cover the whole field of available compositions. Mr. Cheney labored under the disadvantage of doing pioneer work in this field, and so was not able to plan his series as effectively as in better known lines of investigation. Another defect of the series was the solubility of the fritt which acted like so much borax glass, hydrating and giving trouble in drying and burning. Thus the whole ground coat was in fact raw. While this type of ground coat is used to a slight extent, it is not popular among manufacturers and does not give the best results in practice. This, of course, does not detract from the value of Mr. Cheney's work as an experimental study.

In regard to the limits of composition given by Vondracek, little need be said. The B_2O_3 and SiO_2 correspond to American usage. The absence of Al_2O_3 is probably due to the fact that enamel formulae are derived from the glass industry rather than the clay industries. Many enamelers in America now use feldspar in their ground coats. The upper limit of one equivalent of Na_2O is seldom, if ever, reached in this country. The use of CaO as the only RO element in addition to Na_2O is interesting. Lime or other alkaline earths are not used in large quantities in ground coats in the United States. Some PbO or ZnO, or both

are generally present, and K_2O, brought in by feldspar, is a common ingredient.

DISCUSSION.

Mr. Shaw: I never really knew how much difference there was between enameling sheet steel and enameling cast iron until I came here. I never studied the cast iron enamel much. But this cast iron formula agrees with what I have learned from cast iron men, and the cast iron industry is as different from the sheet iron industry as day from night. They are not alike at all. Not only are the formulae different but the methods of application are different, and the heat treatment and the construction of the cast iron formulae. Cast iron men for slush coat make a fritt similar to that given in this paper, and then add raw materials, feldspar, clay, possibly flint, to make a ground coat hard enough to stand the required heat treatment. They burn generally about a thousand degrees I understand. That method does not do at all for sheet steel. The cast iron men usually fritt their opacifiers entirely. The sheet steel men cannot do that. And there are a great many differences which I have found out since I came here that I never knew existed in the two industries. In fact, they are not alike at all and I do not believe I know anything about cast iron, but I hope to find out something about it.

Mr. Binns: Isn't it a fact Mr. Shaw that in the cast iron industry the whole matt is fritted and used dry?

Mr. Shaw: In the case of the cover enamel.

Mr. Binns: Do they use more than one coat?

Mr. Shaw: They use two coats. They have a slush coat, or what we call a ground coat in sheet steel work. There is only a small part of that which is fritted, and they add raw ingredients to make it harder.

Mr. Binns: I know of some cases of cast iron enameling where there is only one coat, and it is all powdered on.

Mr. Purdy: Is it cast iron?

Mr. Binns: I think so.

Mr. Purdy: Kettles and kitchen ware are not cast iron.

Mr. Binns: The sheet steel refers to kitchen utensils. I was including in cast iron the large vats such as we saw at Rochester, and I suppose the powder there was somewhat like they fired on bath tubs. I am informed that only one coat is used and it is put on entirely in a form of a powdered fritt. You do not do that?

Mr. Shaw: I do not see how that could possibly be. Take a bath tub for instance; you have got to heat them to a red heat before you can get the powder to adhere. If you heat it to a red heat, you will have a coating of scale and enamel will not adhere to the scale. I think the practice is in this country at the present time, the general practice, but I would not say that there are not cases where it is not done, but the general practice is to apply a slush coat, and the principal object in that is to form a bond between the iron and the cover coat, and the secondary object is to prevent the iron being oxidized while it is being heated to such a temperature that the powder will adhere.

Mr. Frink: In the manufacture of enameled cast iron, does not the slush coat have another object, to avoid the effect of the graphitic and uncombined carbon? In other words, if we should attempt to put a dust coat on a piece of cast iron, you would have the whole coat completely filled with bubbles, owing to the carbon on the surface or at the surface.

Mr. Shaw: I do not see hardly how that condition would enter. If the carbon is going to effect the cover enamel it would effect the slush coat in the same way. Those bubbles would come out through one coat the same as through the other. It may be that it has some such function as that, but I think that is of minor importance, at any rate, when compared to the union of the iron with the cover coat and to the prevention of the iron from becoming oxidized while heating to such a temperature that

the white will adhere. It may be that you can make a white ground or slush coat for cast iron, but experience in sheet steel work has shown that a ground coat must be colored. I have done considerable work trying to make a light colored ground coat. You can make light colored enamels and apply them as ground coats and get some that will adhere, but if you get a ground coat to adhere it does not matter what its color it when applied, by the time it is burned sufficiently to adhere to the steel, there will be sufficient iron united with the enamel to color it, so that you have got the color at any rate. And the color agents which are ordinarily used on ground coats have the property of causing the enamel to adhere better than enamels which have not these coloring agents. The agents I have reference to are cobalt, nickel and manganese. All three of these have some properties which I do not know, causing enamel to adhere better than enamels that do not contain those ingredients.

Mr. Purdy: It is easy to enamel brass or any other of the metals, but very difficult to enamel cast iron successfully. The slush coat is used to not only prevent the scaling of the iron, but also as a cement, if you will. The metallic oxide forms the bond between the enamel and the cast iron. Color is not the reason for using a given metallic oxide. It happens that the metallic oxides which best forms this bond gives a color. The color is not the main consideration, it is merely co-incident.

Mr. Frink: We find that the free carbon in cast iron unless it is maleable iron prevents our glass from adhering, and I was wondering if this is a parallel condition. If you have those metallic oxides in there, isnt' it possible that that is an added advantage on account of the fact of the small amount of cabon not libeated at the surface going to reduce these metallic oxides? Is that necessarily due to the iron, or may it not be a combination of iron oxide and carbon? You know cast iron does not oxidize nearly as freely as some of the so-called milder steels.

THE EFFECT OF VARYING SIZES AND PERCENTAGES OF QUARTZ GRAINS UPON THE POROSITY AND SHRINKAGE OF KAOLIN.

BY

S. L. GALPIN, Ithaca, N. Y.

Ceramic practice is well acquainted with the general effects produced in clay wares through the admixture of sand or ground quartz. The particular influence of varied percentages and sizes of quartz grains, however, is hypothetically known rather than experimentally proven. The data of this paper have been collected in order to confirm, where possible, the existing theories.

METHODS OF INVESTIGATION.

The experimental work from which these results have been obtained consisted mainly in measuring the porosity and shrinkage of two series of small bricks composed of kaolin, and mixtures of kaolin with varied percentages and sizes of ground quartz.

Series I.

The kaolin used was the washed material from the Harris Clay Company near Webster, N. C., which was easily made ready by crushing. The quartz sands were sized by sieving into the following seven groups: (1) "Finest," a quartz flour showing fairly even grain under the microscope; (2) "150 mesh," sands held on 200 after passing the 150 sieve; (3) "100 mesh," through 100, held upon 150; (4) "80 mesh," through 80, held upon 100; (5) "60 mesh," held upon 80 after passing 60; (6) "40 mesh,'" held upon 60, through 40; (7) "20 mesh," through 20 and held on the 40 mesh sieve.

Mixtures of the kaolin with 10, 20 and 30 per cent respectively of each sand were prepared, made plastic by the addition of water, and moulded, under a pressure of twenty pounds per square inch exerted for three minutes,

into brick (4″x 1″x ¾″). Six test pieces were made from each mixture. On removal from the mould the bricks were allowed to stand for fifteen minutes before marking off the lines by which to measure the linear shrinkage. This was done as the fresher test pieces were easily deformed by slight pressures. Several tests showed a rapid shrinkage in the bricks during the fifteen minute interval between moulding and marking, .75% shrinkage being about the maximum. Usually this shrinkage was greatest in the mixtures from which some water was squeezed during the moulding (and decreased in rate greatly after 10 or 15 minutes). After drying in an air bath the linear shrinkages and weights of the bricks were determined. They were then saturated with kerosene, weighed, and their volume determined in a Seger Volumeter.

After driving off all traces of the oil, the series was divided into six groups, each containing a representative of every mixture. The burning was done in a Seger gas "rund-ofen," and for convenience each group was subdivided into three batches of from six to eight bricks and fired a batch at a time to the desired temperature, or nearly so. The following table shows to what temperatures the different groups were burned:

GROUP	CONE						
I	010	08	1	5	..	..	14
II	010	08	..	5	..	12	..
III	010	08	1	5	..	..	..
IV	010	08	..	..	..	12	14
V	010	08	..	..	9	..	..
VI	010	08	1	..	..	..	..

Measurements of volume, dry and saturated weight were made after each burn, from which the porosity and volumetric shrinkage were calculated, by the following formulæ:

$$\% \text{ Porosity} = \frac{W_1 - W}{V}$$

in which W = dry wt. W_1 = saturated wt., and V = volume.

$$\% \quad \text{Volumetric Shrinkage} = \frac{V_1}{V}$$

where V = volume of dry unburned brick, V_1 = volume after burn in question.

The results were averaged whenever possible and plotted upon curves, which, although showing some points well, were rather irregular to be satisfactory, and for that reason a new series of bricks was prepared and tested as follows:

Series II.

Kaolin was mixed with 10, 20, 30 and 40% respectively of the "finest" 100 mesh, 60 mesh and 20 mesh sands, greater care being taken to secure uniform plasticity for all mixtures when preparing them for the mould. In making some of the bricks for the first Series, the pressure of 20 lbs. per square inch was so great that water was squeezed out of the clay, softening the sides and edges of the brick, and causing warping. In order to avoid this the bricks of Series II were made under a pressure just sufficient to fill the corners of the mould thoroughly.

In burning, the groups of bricks were so arranged that comparisons could be made between any two groups at the same burn, and where obvious corrections were made for over or under burning. Each group was fired successively to 2240°F (1226°C) or Cone 5), 2370°F (1300°C) (or about cone 8½), 2410°F (1321°C) (Cone 9½); temperature measurement being done with thermocouple and pyrometric cones. The burns were carried on slowly in order to secure thorough and uniform heating throughout the muffle.

The results of series I were satisfactory for burns at cones 010 and 1, and these burns were omitted for that reason in the firing of the second series. As yet the mixtures of series II have not been burned above about cone 9½, although it is intended to carry them as high as cone

14 or 15. Series one was carried up to cone 14, and even at that temperature the shrinkage and porosity changes showed no great progressive irregularities.

Duplicate detrminations of specific gravity, porosity and volumetric shrinkage were made, and averaged for the final results which, for convenience, have been plotted upon the accompanying charts. The Sp. G's. were determined by the formula:

$$\frac{W}{V - A} = \text{Sp. G.}$$

where W = dry weight; V = measured volume; A = absorption.

Explanation of Charts.

Chart No. 1 shows in the first column the percentage of water in the plastic dough. The irregularities in the curve representing the results for the finest quartz mixtures are due to experimental error. Comparison of the

Chart No. I

four curves shows, however, that an increase either in the percentage of quartz or in the size of the grain reduces the

amount of water required to produce a uniform plasticity in the mixtures. It would seem that theoretically these curves should be straight lines, at least for the coarser textures.

The second column of curves represents the plotted results for porosities of the green mixtures. The great irregularity of the upper curve is thought to be dependent upon the irregularities of the percentage water curve for the same mixtures. That is to say, if too little water is added in mixing a clay, a higher value for the porosity will result than that obtained when the proper amount is used. The dotted line in the third curve of this column represents a correction which duplicate test pieces indicated should be made. The porosity curves show that increase in size of grain or percentage of quartz (within the limits of the experiment) decreases the porosity of the unburned mixtures.

Column three represents the effects of varying mixtures on linear air shrinkage. The upper curve of this

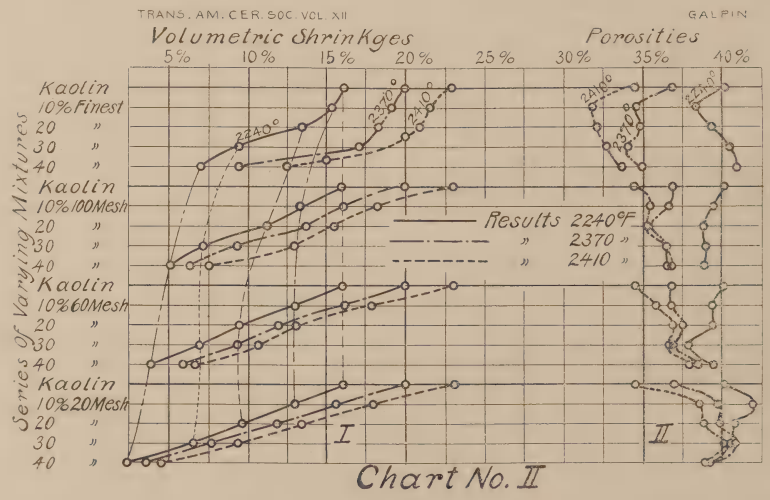


Chart No. II

series should also be corrected for the irregularities in the amounts of water added to the various mixtures. Too

little water in the mixture would reduce the air shrinkage, and the low contraction shown by the 40 per cent mixture is thought to have been caused in this way. It is not best to place too much reliance upon the results for linear shrinkage, as they are usually rather irregular. They seem to show a decrease of shrinkage with increase in size of grain, or with increase in percentage of quartz added to the mixture.

Chart No. II shows the volumetric shrinkage and porosities for the mixtures after three separate burns, the first to 2240°F (1226°C); the second to 2370°F (1300°C); and the last to 2410°F (1321°C).

In the first column are the curves showing the changes in volumetric shrinkage when the percentage of quartz is increased in the mixtures. It may be seen that the effects are regular for the three coarser textures, at each burn, but that with th finest mixtures there is a decided increase in the shrinkage of the 10 and 20 per cent mixtures. The 30% mixture shows a large increase between the first and second burns, but at the last burn the increase is proportionally less.

The second column shows curves of average porosity for the same burns represented in column I. At the first glance they seem hopelessly irregular, but further study develops some general regularities. Beginning with the upper series it appears first, that 10% of the finest quartz reduces the porosity in increasing proportion with the higher burns, as shown by the dips of the upper limbs of each curve. The 20% mixture shows less reduction of the porosity at the first burn, but at the succeeding ones shows a greater proportional reduction. The 30 and 40% mixtures show an increased porosity over the neat kaolin at the lowest burn, but with the higher two, they show a proportional reduction of porosity especially marked at the second burn.

The curves for the remaining mixtures show, in general, the opposite tendency, i. e., at the lowest burn the

mixtures reduce the porosity with increased percentage of quartz, while at the two higher burns they increase the porosity as compared to that of the neat kaolin, although there is a real decrease from burn to burn except in the 30% mixture of 20 mesh quartz, which shows an increase between the first two burns, but thereafter a decrease. It may also be noted that the higher percentage mixtures of of the three coarser textures show much smaller changes in porosity at the different burns than do the lower percentages.

Chart III represents the effect of increasing the size of grain of the quartz on the shrinkage and porosity of the mixtures for two burns, the heavy lines representing values obtained after the burn to 2410°F (1321°C) and the

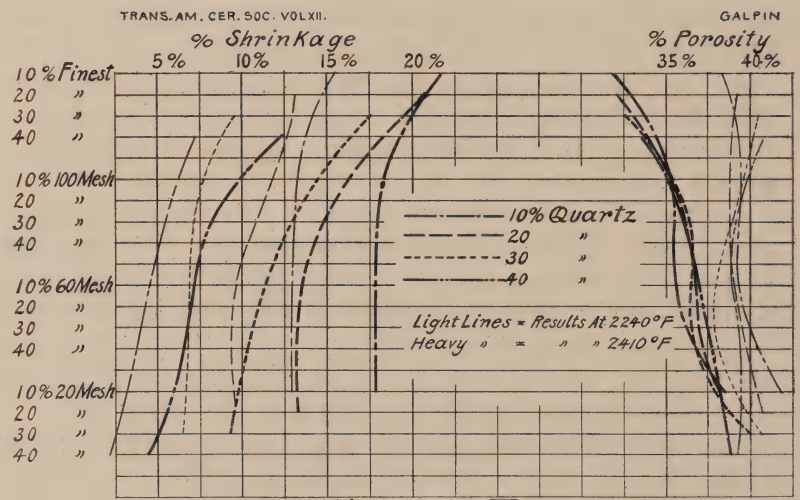


Chart No. III

lighter lines showing the results after the burn to 2240°F (1226°C). The results obtained after firing to 2370°F (1300°C) are not plotted, as they seem in every respect intermediate between those shown.

It may be noted that most of the curves show a rather

sharp deflection between the "finest" and the 100 mesh mixtures. This is due to the fact that the values for the finest mixtures have been plotted on the curve, as if there were no greater difference in size of grain between the "finest" and 100 mesh, than between the 100 and 60 mesh. The result is a foreshortening and consequent deflection of the curves.

Examination of the curves upon the left side of the chart will show (1) that for the shrinkages at the lower burn there is regular decrease with increase of size of grain, the coefficient of this decrease varying directly with the percentage of quartz in the mixtures. That is, the reduction of shrinkage by increase in size of grain is

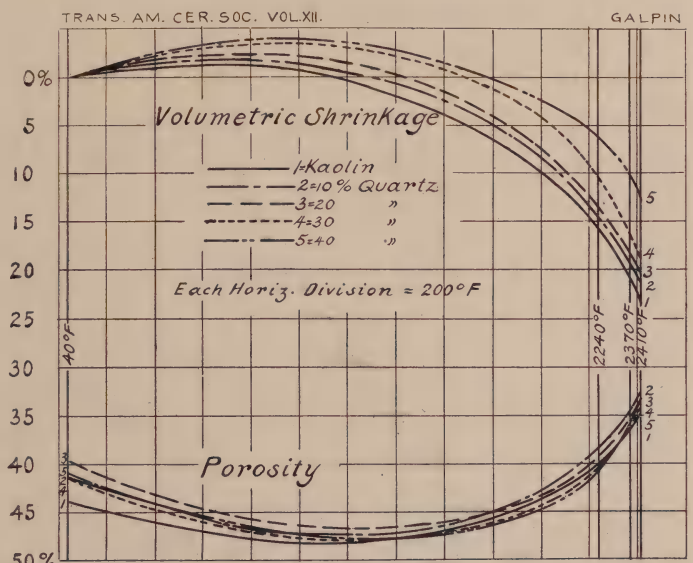


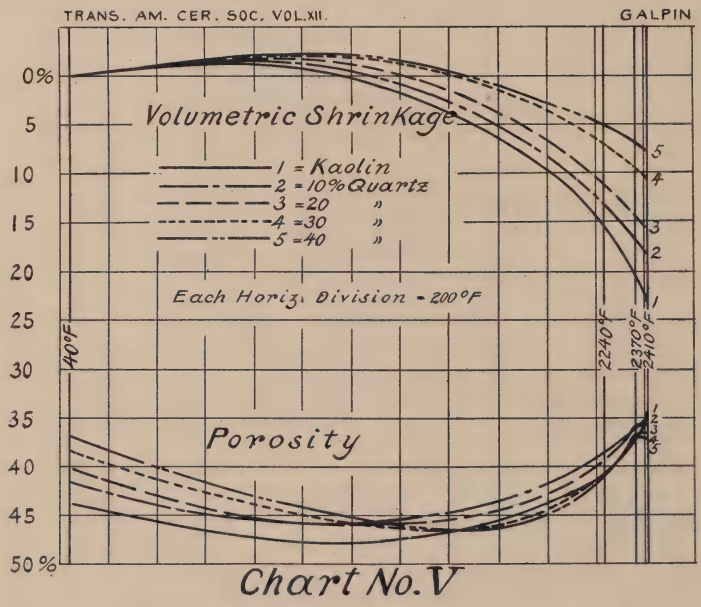
Chart No. IV

about twice as great for the 20% mixtures as for the 10%, and so on.

(2) The same relation seems to hold for the results at the higher burn. Comparison of the curves of shrink-

age for the two burns shows that the coarser mixtures are affected less with the succeedingly higher burns than are the finer mixtures.

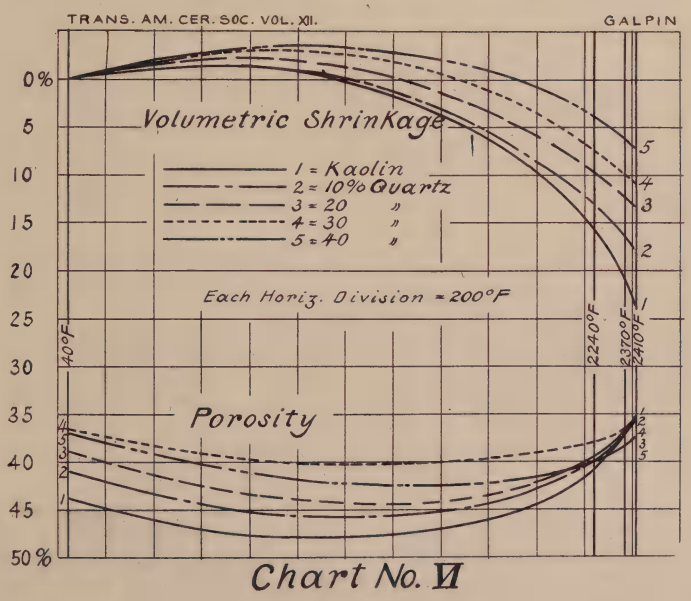
The curves of the porosity results fall into two groups according to the temperature to which the mixtures had been burned. It may be seen that at the lower burn, the increase in percentage of the finest quartz in the mixtures increases the porosity, while the opposite is true in the case of the 20-mesh mixture. The 100-mesh mixtures represent one of the transition stages. The effect of the size of grain on the different mixtures burned to 2240°F (1226°C) seems to be roughly as follows: Increase in size



of grain on (1) ten per cent mixtures increases the porosity, (2) twenty per cent mixtures increases porosity to a less degree, (3) thirty per cent mixtures decreases porosity down to 60 mesh size, increasing it with the coarser textures, (4) forty per cent mixtures decrease the porosity slightly.

Considerable similarity is shown by the curves for the higher burn to those of the lower, the difference being mainly in relatively greater reduction of porosity in the finer-textured mixtures than in the coarser ones. It may also be seen that incretse in size of grain in the mixtures is accompanied by a corresponding increase in porosity.

Chart IV, V, VI, and VII represent the progressive changes in shrinkage and porosity at succeedingly higher burns. The upper curves represent the fire shrinkages with a value of 0 at 40-60°F, with the porosity shown by the green mixtures. The lower curves show the porosity changes starting at 40°-60°F. It is readily seen that the differences in porosity are less in the burned wares than the differences in shrinkage. Furthermore, the porosity of the unburned mixtures seems to affect the position of their curves, especially in the finest mixtures. Although



the actual porosities do not show it, the curves indicate the relative changes in porosity and shrinkage well.

In chart IV, the curves indicate that the mixtures are decreasing in porosity more rapidly than the neat kaolin, while the shrinkage curves show that at the higher temperatures the rate of contraction of the mixtures is close to that of the kaolin.

Charts V, VI, and VII, show in general the rate of increase in shrinkage and the rate of decrease in porosity with rising temperatures are less for the quartz mixtures than for the neat kaolin, the higher the percent of quartz the lower the rate of change in both porosity and shrinkage. The peculiarities of the porosity curves for the 100 mesh mixtures should be noted. The higher percentage

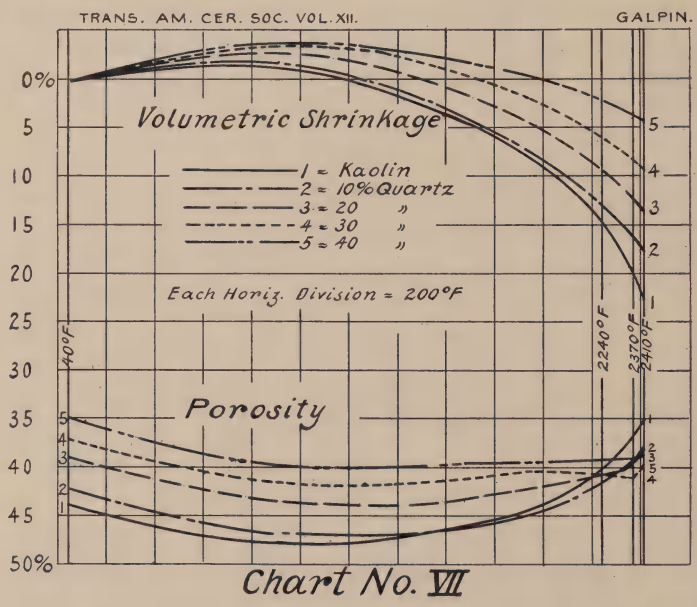


Chart No. VII

mixtures show little or no change in porosity for the higher burns. Charts VI and VII do not show similar results.

Chart No. VIII shows the changes which take place in the specific gravity, in the different mixtures. For the finest mixtures it is seen to decrease more rapidly in the

test pieces up to 20% quartz, the higher percentages showing a lower rate of decrease. In the coarser mixtures the density decreases from the first to the second burn, but increase with the last and highest firing, the effects being more pronounced for the 100 and 20 mesh mixtures than for those of 60 mesh. The points of maximum specific gravity represented upon these curves are conjectural, the determinations being made only on the green brick, and after each of the three burns as indicated on the chart.

Interpretation of Results.

An interpretation of the foregoing results is problematic but interesting. The mixtures tested may be said to be composed of two kinds of substances (1) crystalline and (2) non-crystalline or colloidal. Fine grinding reduces the crystalline substances to a finer texture, and the theoretical limit of the subdivision of the crystalloid par-

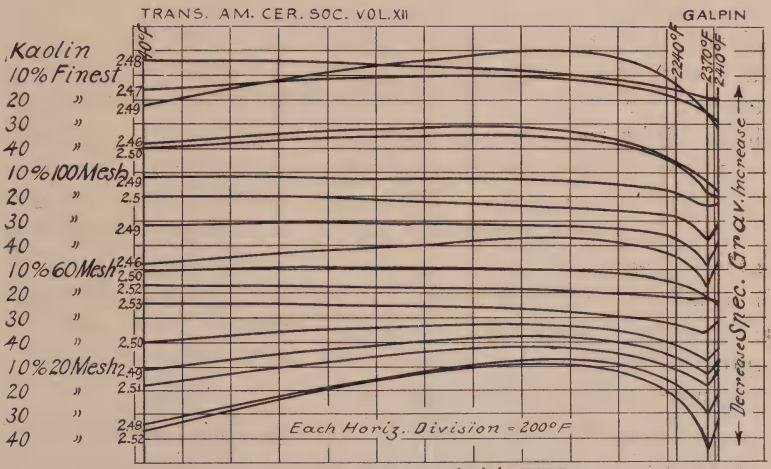


Chart No VIII

ticles would be the molecule at which point the substance would become colloidal, that is, composed of molecules having no definite arrangement with each other. Particles or grains of this colloidal substance are more easily broken

down into molecules than are crystalline grains, so much so in fact that the addition of water is sufficient in some cases to bring about "deflocculation." In other cases the presence of some electrolyte is required to accomplish this disintegration. The crystalline particles remain intact when water is added to them, the bonds of crystallization holding the molecules together. The result is that a given amount of colloid will expose a much greater surface, in proportion to its mass than a crystalloid, from which it follows that the effects of surface tension will be proportionally greater in the colloid.

It seems safe to assume that practically all clays are composed of crystalline and non-crystalline particles, which become surrounded by thin films of water when the clay is tempered. Some, or at times nearly all, of the colloidal particles disintegrate into molecules in the presence of water, and each molecule becomes surrounded by a thin film. These thin films greatly reduce the internal friction of the clay mass allowing deformation under pressure, but preventing rupture mainly through their surface tension phenomena. (It seems that intermolecular attractions might tend to hold the mass together, but they are supposed to be slight in colloidal substances.) The fine grinding of crystalline substances develops, to a slight degree, similar properties, and the addition of deflocculating agents to clays increases this property in them, by increasing the actual amount of wetted surface. It would seem then that plasticity is a phenomenon, based directly upon surface tension, and developed mainly through the presence of colloidal substance.

As a wetted clay dries the films of water surrounding the particles become thinner, drawing the clay molecules together, resulting in "air-shrinkage." The amount of this depends largely upon the amount of colloidal matter and the presence of coarse particles, which may form bridge-like structures within the clay; the former increases while the latter hinders the shrinkage of the whole. The results

obtained from measurements of the kaolin-quartz mixtures, agree with this view. The greater shrinkage in the finer grained mixtures is probably due to the greater surface tension developed in them. The reduction of the amount of water used in tempering the coarser mixtures corroborates this point.

The addition of non-porous particles to a porous mass should reduce the porosity in that mass to a point where the added particles become so numerous that the spaces between them are not entirely filled by the original substance. The results obtained are not at variance with this view. (See chart I.)

When the kaolin-quartz mixtures were heated they first expanded and became more porous up to a temperature somewhere below cone 010. At higher temperatures contraction began and increased with greater heat as indicated on charts IV to VII. The expansion may be attributed to "permanent swelling," and the increase in porosity to the same, aided by the loss of water from the hydrous clay minerals. The subsequent contraction is ascribed to the fusion of some particles in the clay, the liqid formed exerting surface tension on the surrounding particles, drawing those free to move closer together. The addition of a non-fusing substance would retard the shrinkage by lowering the amount of fusible material. The mixtures of high quartz percentages, and especially those of coarser grain, would seem to retard the shrinkage further by the formation of a more or less solid frame work of quartz grains through the clay, which would, at the same time, increase the porosity. The finer the texture the less the tendency to form these frameworks because of the more even distribution of quartz and kaolin. An examination of Charts II and III shows that the experimental evidence favors this view.

The progressive changes shown in the specific gravities for the members of the series are interesting (See chart VIII). It seems certain that the increase in specific

gravity of the bricks does not represent an actual increase in the specific gravity of the particles, as they should show the reverse with rising temperature. The only plausible explanation would then be on the grounds of change in porosity. That is to say: those bricks which show an increase in specific gravity from 2370°F to 2410°F, do so because some closed pores or gas spaces have been opened up, giving a more nearly true result. Examination of the porosity results strengthens this view, while the test pieces themselves almost confirm it, as the mixtures showing a reduced specific gravity are found to contain many rounded vesicles which are less frequent in the others. As mentioned above, the fine-grained mixtures would probably tend less to form frameworks of quartz, which would aid the formation of a dense body. In the case of the coarser grains there would be the opposite inclination, in fact it seems probable that closed pores would be torn open by the surface tension of the fused substances, because of the solid foundation of quartz grains away from which the clay would pull, forming open channels increasing the measurable porosity.

CONCLUSIONS.

The practical conclusions which it seems may be drawn from the results of the experiments are summarized as follows:

I. The addition of ground quartz to a refractory clay reduces its air and fire shrinkage directly with the amount added.

II. The porosity of the green wares is reduced, that of the burned wares increased by the addition of quartz grains. (This holds only when there are no substances present which will flux the quartz).

III. The admixture of quartz reduces liability to warping and cracking of the burned wares.

IV. The fine-grained mixtures tend to produce gas vesicles at higher temperatures.

V. The greater percentage of quartz in the mixtures the less water used in tempering.

VI. The coarser the grains in the mixtures, the greater the reduction of shrinkage and the less the reduction of porosity; the less water required in tempering, the less the tendency to warp or crack in burning; the fewer the gas vesicles formed in the ware.

The experimental work from which these conclusions are drawn was carried on in the geological laboratories at Ithaca under the direction of Professor Ries. The materials used were gratuitiously furnished by the Harris Kaolin Company and the New England Quartz and Spar Company. It is hoped that further progress with the tests may soon be reported.

THE RELATION BETWEEN THE POROSITY AND CRUSHING STRENGTH OF CLAY PRODUCTS.*

BY

A. V. BLEININGER, Pittsburg, Pa.

It is evident that the compressive strength cannot be correlated with the porosity for all clays, but that such coordination must be restricted to the same clay made into the shape to be tested under uniform conditions. The crushing strength of burnt clay increases primarily with the hardening of the material itself, and secondarily with the decrease in pore space. Again, no product is uniformly strong in all directions; according to the method of manufacture it will be stronger along one plane than along others. Also, the question of abnormal structure, such as auger lamination, enters as an important factor.

Owing to the fact that clay products in actual use are never taxed beyond a small proportion of their ultimate strength, this whole problem would appear to be largely an academic one, were it not that the compressive strength serves as a criterion for the differentiation between the various grades of clay brick or the comparison between clay and other makes of bricks, such as those made by the sand-lime process.

For the first purpose it seems necessary, in order that it may be possible to adopt specifications insuring to the user products of reasonable strength. Any one familiar with the various grades of bricks used throughout the country is aware of the fact that the quality considered satisfactory in one city would be rejected in another. While for most practical purposes this, perhaps, would not be an important matter, yet in certain types of construction, such as piers used for warehouses or for carrying heavy machinery, it becomes a desideratum. The tendency to use lighter walls to compete with concrete, the

* By permission of the Director, U. S. Geological Survey.

competition between clay, sand-lime and cement brick, and the necessity of possessing requirements capable of legal interpretation, are all reasons why more attention should be given to this subject. Again, it does not seem fair to make no differentiation between a well made and well burnt product and an inferior one, as is now the case in many places. At present the average contractor looks more to cheapness than quality.

Steps have been taken to remedy this condition, and the National Underwriters' Association, the American Society for Testing Materials and the Technologic Branch, U. S. G. S., have adopted preliminary specifications governing building brick. Those of the American Society for Testing Materials may be taken to express the average requirements of these specifications, and briefly they are as follows:[1]

Tests required:
1. Transverse Test.
2. Compression Test.
3. Absorption Test.
4. Freezing and thawing tests.

In the transverse test the brick is laid flatwise with a span of 7 inches. The modulus of rupture should correspond to the following values:

	Average	Minimum
Sample thoroughly dry.....	400 lbs.	325 lbs.
Thoroughly saturated	275 lbs.	225 lbs.
After freezing and thawing.....	275 lbs.	225 lbs.

In the compression test the half bricks resulting from the transverse test are used. The bricks are bedded flatwise, even bedding being secured by the use of blotting paper, or better by means of plaster. The requirements are:

	Average per sq. in.	Minimum per sq. in.
Sample thoroughly dry.....	3000 lbs.	2500 lbs.
Thoroughly saturated	2500 lbs.	2000 lbs.
After freezing and thawing.....	2500 lbs.	2000 lbs.

[1] Proceedings Am. Soc. for Testing Materials, Vol. 9, p. 131.

In the absorption test five half bricks are immersed in water to a depth of 1 inch in a covered container. After 48 hours the absorption shall not be more than 15% of the dry weight of the bricks.

In the freezing and thawing tests five whole bricks are saturated with water, immersed in ice water for one hour and then subjected to a temperature of less than 15° F. for five hours, all faces of the samples being exposed. The bricks are thawed in water of not less than 150° F. for one hour. This is to be repeated twenty times. No cracking or serious spalling or disintegration shall be caused by this treatment.

The committee which drafted these specifications wisely considers them as tentative, and it is evident that there are several points which need further discussion. These include such questions as the method of carrying on the compression test, the determination of the permissible absorption limit, the method of making the transverse test, the simplification of the freezing and thawing test, the value of determining the rate of water absorption, and several others.

It is proposed in this paper to take up only the first two points.

The testing of half bricks bedded flatwise, which unfortunately is a common practice, is seriously handicapped by the large experimental error due to the shape. Any one who has done brick testing is familiar with the fact that it is a difficult matter to determine the failing point of the specimen, and frequently it is observed that the load will continue to rise in spite of the fact that the brick has gone to pieces and seems to show a kind of gradual flow. Without attempting to give figures, the fact remains that the error certainly is large. Theoretical considerations show that the cube or, still better, the prism of square cross section, the height of which is one and one-half times the breadth, gives best results, which is shown by the symmetrical appearance of the fracture planes. In the German practice of making brick tests, two half bricks are cemented

together by means of a thin Portland cement mortar joint to form a prism, and the results obtained in this way appear to be very satisfactory. However, this method does not seem to find favor in American testing, though it has much to recommend it. The only alternative, then, is the testing of the half brick bedded on edge. From the work already done on edge testing it appears quite evident that this method is a great improvement upon the flat test, inasmuch as the failing point is distinguished sharply, thus overcoming the great objection to the old procedure. In carrying out the test, the whole brick placed on some soft material like burlap is cut in two, along a line drawn across, by means of a sharp, wide chisel. The edges of the specimens are then made parallel on a plate glass rubbing plate, using a thick plaster of paris paste and testing with a delicate spirit level in two directions. It is good practice to coat the surfaces of the brick coming in contact with the plaster with shellac, allowing the latter to dry before trueing up. The bricks thus treated should be tested on the same day if possible, as the thin plaster coating is liable to warp some, especially if the bricks are not shellacked. The testing machine should be equipped with spherical bearing blocks.

The natural objection to testing the bricks on edge is, of course, the fact that they are not placed in this position when used. This point, however, is not of importance, since the compression strength *per se* has no practical value excepting as it differentiates between good and poor materials. Since the flat test is handicapped by serious experimental errors, it is evident that the advantage must be with the method crushing the specimen on edge, which at least furnishes more reliable data for purposes of comparison.

It is impossible, however, to calculate from the compressive strength on edge the strength when tested flat, or vice versa, excepting for one and the same make of brick, owing to the fact that the structure plays an important

part in this connection. It is evident that the side cut brick is bound to show a different compressive strength, when tested on edge, from the end cut made from the same clay. It seems then that we can compare only side cut with side cut or end cut with end cut bricks, and even in doing this considerable discrepancies, due to structure effects, are bound to appear. In order to avoid confusion then no attempt should be made to refer the compression strengths to the strength when tested flatwise, but comparison should be made simply on the basis of the edge test. If, thus, end cut bricks show different strengths from side cut, this cannot be helped.

The relation between the strengths of half bricks tested flatwise and those tested on edge is clearly shown in the diagram of Fig. 1, representing 176 tests. Here the whole bricks were cut in two, one half was tested flatwise, the other on edge. The samples were collected by Mr. H. E. Ashley in a district covering a radius of 150 miles from Washington, D. C. The bricks tested were of the harder grade, and practically all of them made by the stiff mud process. This work was done at the request of the Supervising Architect, with instructions to collect only materials of superior quality. Both shale and clay brick are represented.

Using only the true averages, i. e., results in which the samples were subjected to tests both flat and on edge, we find the mean value for the flat test to be:

$$\text{a.}\quad \frac{109584}{176} = 6226 \text{ pounds per square inch.}$$

The average for the edge test is:

$$\text{b.}\quad \frac{950212}{176} = 5399 \text{ pounds per square inch.}$$

$$\text{The ratio}\quad \frac{\text{a}}{\text{b}} = \frac{6226}{5399} = 1.153.$$

In the diagram, Fig. 1, the straight line represents this ratio between the two kinds of tests. It is evident that

the individual tests vary widely from the average ratio on each side of the line.

In this connection it is important to recollect that the flat tests represent a value of accuracy considerably lower than that for the edge tests and this is the source of a good many of the variations, without in the least neglecting the consideration of the structure effect.

The second point it is proposed to take up is the relation between the porosity (as measured by the water absorption) and the crushing strength (on edge). It is proposed to carry on an extensive series of tests along this line in connection with freezing tests. At the present time only a small fraction of the proposed work can be reported, which consists of three test series.

A. The correlation between the water absorption and crushing strength of 178 bricks, chiefly stiff-mud, representing the work done for the Supervising Architect mentioned above.

B. A series of tests made on stiff-mud shale bricks of medium grade, assorted by means of absorption tests into 14 groups, 10 bricks being used of each. These bricks are from the same yard and have been made under the same conditions, subject to the variations in the mixture of the several strata in the bank. They are side-cut bricks.

C. Compression strength tests of cylinders about $3\frac{1}{8}$ inches in diameter and $7\frac{1}{8}$ inches high. These were part of three series of cylinders $3\frac{1}{8}''$, $4\frac{1}{4}''$ and $6\frac{1}{8}''$ in diameter, with heights of $7\frac{1}{8}''$, $7\frac{3}{4}''$ and $12\frac{3}{4}''$. The main purpose of making these cylinders was the determination of the modulus of elasticity for different burning temperatures and, of course, incidentally the crushing strengths and porosities. Unfortunately, however, it was found that the auger structure developed gave rise to serious difficulties in testing, which rendered the specimens almost useless for the purpose for which they were intended, in spite of the fact that in external appearance they seemed to be of good quality.

A. The results of this series are presented in Table I. Side-cut bricks are indicated by (-), end-cut by (x) following the sample number, and if repressed, by the letter R. Those marked (*) are hand made. The compression strength is given for both the flat and the edge test, though only the latter is used for purposes of comparison. The absorption was determined by placing the bricks flat in water to a depth of one inch and keeping the soaking tank covered. After 48 hours immersion the bricks were again weighed and the absorption expressed in terms of the dry weight.

There is no doubt but that where strict accuracy is desired the absorption should be carried farther by artificial aids, such as boiling and evacuating, and at the same time the true and apparent specific gravities should be determined to permit of the calculation of the actual porosity.

TABLE I.

No.	Crushing Strength		Absorption %	No.	Crushing Strength		Absorption %
	Tested on Flat, lbs. per sq. inch	Tested on Edge, lbs. per sq. inch	by weight, in terms of dry brick		Tested on Flat, lbs. per sq. inch	Tested on Edge, lbs. per sq. inch	by weight in terms of dry brick
1-	14,560	8,479	.13	36x	4,600	5,920	9.13
2-	13,880	6,200	1.37	37*	3,750	3,440	14.72
5-	14,550	7,880	1.45	38*	6,640	5,223	13.45
6-	15,900	11,740	1.39	40x	7,980	.....	8.31
7-	18,790	13,260	1.11	41x	6,750	4,990	10.47
10-	6,570	7,260	6.38	43x	6,660	3,880	11.21
11-	5,020	3,768	10.05	44x	5,720	4,680	11.90
12-	4,180	3,100	13.65	45x	4,650	5,330	12.68
13-	5,480	4,220	11.70	46x	3,080	2,892	14.45
15-	12,450	5,130	.....	47x	4,230	3,832	13.91
17-	10,650	5,660	.....	49x	1,730	.....	18.47
18-	15,300	9,270	.....	50-	16,150	6,480	0.30
19-	10,660	7,880	.....	51-	9,420	4,820	4.69
21-	6,710	6,320	7.35	53-	8,270	5,665	6.35
23-	7,250	6,315	7.78	56-	6,380	3,360	8.28
25-	4,330	3,720	7.74	58-	5,640	6,615	12.39
28-	4,880	5,770	10.03	59-	.....	1,795	20.28
29-	6,550	6,365	8.97	60-R	2,590	2,630	11.46
30-	5,510	5,960	10.04	61-R	3,140	4,185	12.34
31-	6,610	6,230	9.04	63-R	2,670	2,916	15.21
33-	9,470	**	7.05	65-R	4,900	3,930	10.08
34x	**	6,610	20.90	66-R	4,170	3,160	10.87
35x	4,780	4,350	14.83	67-R	2,880	2,900	14.33

TABLE I—CONTINUED.

No.	Crushing Strength Tested on Flat lbs per sq. inch	Crushing Strength Tested on Edge lbs. per sq. inch	Absorption % in weight, by terms of dry brick	No.	Crushing Strength Tested on Flat lbs. per sq. inch	Crushing Strength Tested on Edge lbs. per sq. inch	Absorption % by weight, in terms of dry brick
68-	2,530	2,364	14.94	142-	5,710	6,225	10.14
70-	3,860	4,450	10.50	143-	5,450	5,312	11.35
71-	7,430	5,423	8.92				
72-	5,950	3,725	8.15	145-	4,780	6,470	11.03
73-	7,850	5,545	5.74	146-	6,480	4,230	10.50
75-	7,180	7,395	4.36	149-	6,020	5,285	10.34
78-	4,980	3,924	4.34	150-	4,030	4,095	12.32
79-	7,220	6,730	4.45	151-	5,400	3,815	11.76
80-	8,900	6,330	3.21	153-	5,100	4,030	11.96
81-	2,105	1,850	9.15	154-	3,315	2,580	16.65
82-	2,674	2,555	11.77	156-	4,210	3,710	14.51
83-	2,748	2,133	9.57	158-	4,650	3,025	14.25
84-	3,330	3,640	8.03	160-	3,330	1,990	16.63
85-	2,546	3,345	6.44	161-R	.....	2,122	7.48
86-	3,350	5,330	5.43	162-R	5,160	5,300	9.21
89-	5,770	7,730	3.42	164-R	3,620	2,903	10.06
90-	7,180	9,640	2.02	167-R	1,683	1,242	18.81
92x	.....	8,645	8.92	168x	3,400	2,360	16.21
93-	3,410	2,673	10.72	169x	4,200	3,010	13.69
94-	3,710	4,890	9.01	170x	5,600	4,320	7.95
96-	13,370	11,670	3.01	172x	713	.....	22.45
98-	10,630	11,700	2.54	173x	5,810	4,690	5.72
100-	11,900	12,440	2.42	174x	6,750	4,500	9.92
102-	3,577	3,925	4.93	175x	5,400	4,490	11.70
103-	4,620	5,076	12.90	177x	10,550	9,500	3.99
104-	9,380	10,460	0.81	178-	2,140	1,225	20.46
106-	10,000	13,500	1.14	179-	2,090	1,283	17.42
107-	12,390	11,590	0.73	180-	3,430	1,798	15.95
110-	8,520	9,880	0.71	181-	3,130	1,952	16.80
112-	3,380	647	12.15	182-	5,240	2,970	10.83
113-	6,750	7,770	7.29	185-	6,470	3,150	5.13
115x	9,150	15,520	1.02	186-	6,120	6,320	1.37
117x	4,770	6,760	8.52	188P	3,430	852	11.76
118x	5,640	8,860	6.17	189	5,020	972	9.17
119x	12,930	21,040	0.26	191	4,050	2,690	8.18
120x	11,540	15,300	0.00	192	4,130	4,600	6.60
122x	7,700	5,880	1.66	194	4,590	4,850	6.26
123x	5,260	5,230	5.09	195	6,430	6,270	6.53
124x	5,860	5,285	5.68	196	5,020	4,980	5.83
125x	5,430	2,925	8.80	197	4,620	7,140	5.44
126x	2,450	1,436	17.34	198	6,020	4,346	6.02
127-	5,730	6,370	8.32	199	4,490	5,150	7.28
128-	5,380	5,800	8.44	200	4,970	5,230	6.33
136-	5,140	6,475	10.37	202	5,400	4,369	5.46
137-	5,480	5,720	10.66	203	8,650	3,360	5.98
139-	5,180	7,625	10.19	205	5,320	3,830	7.96
140-	5,170	5,270	10.68	206	9,950	5,540	4.43
141-	6,120	4,575	10.32	207	6,800	3,150	5.52

TABLE I—CONTINUED.

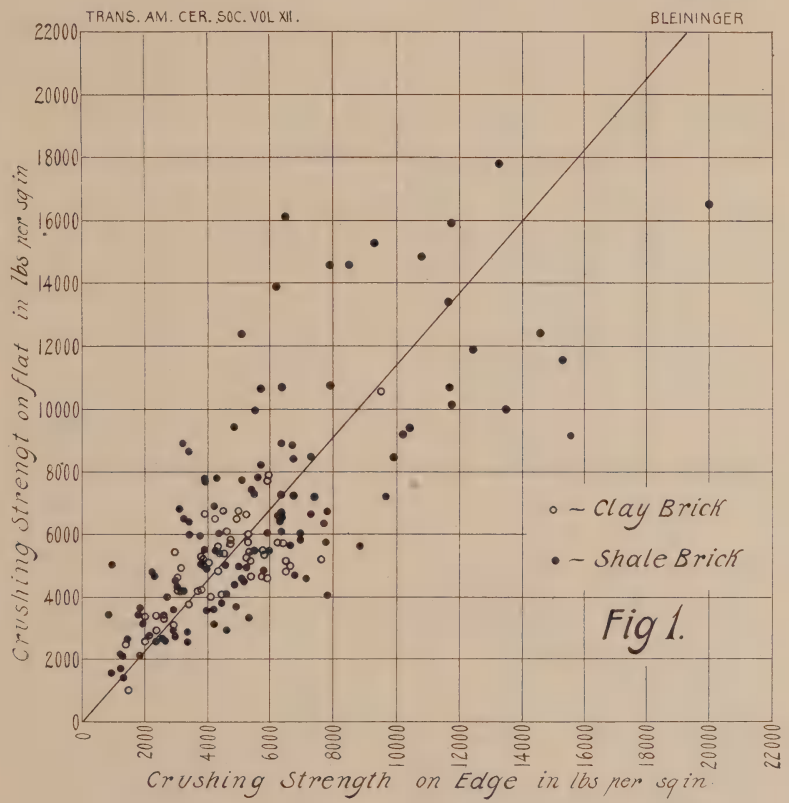
No.	Crushing Strength Tested on Flat lbs. per sq. inch	Crushing Strength Tested on Edge lbs. per sq. inch	Absorption % by weight in terms of dry brick	No.	Crushing Strength Tested on Flat lbs. per sq. inch	Crushing Strength Tested on Edge lbs. per sq. inch	Absorption % by weight. in terms of dry brick
208-	.....	4,520	9.42	244x	1,970	1,610	19.50
210-	7,740	3,880	7.05	245xR	4,280	3,740	11.74
211-	5,530	3,780	8.24	246xR	4,930	3,150	12.45
212-	5,270	3,030	12.20	249-	10,680	6,330	3.88
213-	4,290	3,150	14.96	250-	.....	3,910	4.00
214-	4,540	2,950	16.39	252-	7,830	4,260	4.17
215-	4,810	3,470	13.86	255-	8,870	6,670	3.44
216-	1,530	953	20.51	256-	6,080	5,870	5.47
217-	6,000	3,380	9.07	257-	8,450	6,630	4.92
218-	8,820	3,150	6.72	258-	5,510	5,410	7.29
220-	6,930	4,180	9.17	259-	6,030	6,960	6.29
221-	7,770	5,070	14.32	260-	7,300	.....	7.76
222-	5,040	4,530	13.36	261-	.....	6,350	8.06
223-	3,640	1,925	21.80	262-	2,960	4,570	11.81
224-	4,690	2,275	20.02	263-	3,600	4,180	11.63
225-	.....	3,550	16.66	264-R	7,340	5,480	3.44
228-	2,600	1,414	23.10	265-R	8,480	7,270	3.04
230x	7,880	5,920	8.25	267-R	5,830	6,950	5.39
231x	6,480	4,920	12.15	269-	14,860	10,770	0.94
233x	4,980	6,670	11.22	270-	16,510	19,940	1.98
235x	4,620	4,680	15.76	271-	9,170	10,200	8.04
236x	4,030	4,520	12.70	272-	6,360	7,680	11.27
239x	.....	1,550	18.81	274-	1,396	1,337	18.90
240x	2,530	1,960	17.62	275-R	10,140	11,750	5.35
241x	2,940	2,390	16.47	276-R	4,060	7,670	9.65

However, since the main purpose of this part of the work was to deal with practical testing conditions, it was decided to make use only of the absorption values expressed in terms of the weight of the dry brick. In the main investigation, in which different types of clays are correlated as to their gain in strength, which now is under way, the true and apparent porosities are employed.

In Fig. 2 the results of the 178 brick tests (on edge) are combined in a general curve. Since the samples have been collected from a number of yards and represent both shale and clay brick, we should not expect any close agreement. The bricks have been divided into groups according to their absorption. Thus, a sample showing an absorption of 15.7% would come into the 16% group, while one with 15.2% would be included in the 15% group.

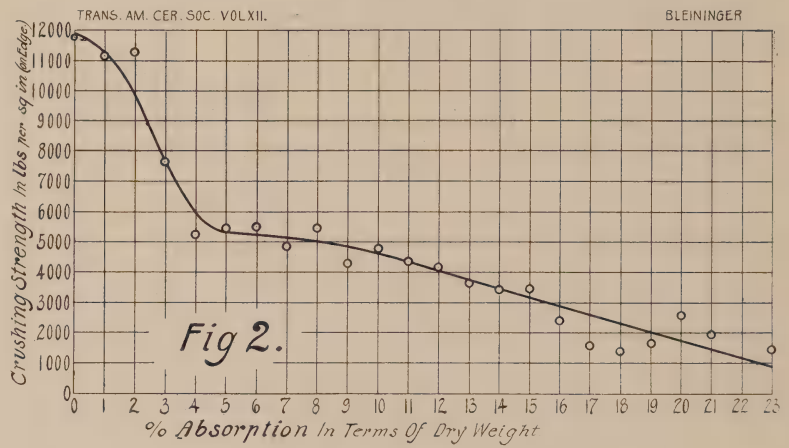
It is surprising that the correlation is as satisfactory as it is, considering the many factors affecting the results. One fact noted is that the repressed bricks show a lower strength than the unrepressed.

On examining this generalized curve, it is observed to consist of two parts, viz., approximately a straight line



from maximum down to 5% absorption, and a short, steep part from 5 to 0% absorption. None of the bricks were overburnt as far as could be observed by eye, and hence the downward course of the curve is not in evidence. It seems quite clear that in the steep portion of the curve the

strength increases, due both to the gain in the inherent strength of the solid vitrified clay and to the decrease in pore space. The former evidently is the major, the latter a very minor factor. We might say then that the com-



pressive strength of the bricks up to the critical turning point of the curve may be expressed approximately by the relation:

$$C = K\frac{1}{p}$$

where C = crushing strength.
p = % absorption or more accurately % porosity.
K = a constant.

TABLE II.

% Absorption	Max. Load lbs.	B ins.	L ins.	Average Crushing Strength lbs. per spu. in.	% Absorption	Max. Load lbs.	B ins.	L ins.	Average Crushing Strength lbs. per sq. in.
3-4	71,450	2.33	4.26			64,400	2.36	4.10	
	62,000	2.34	4.24			46,450	2.37	4.27	
	52,530	2.30	4.17			54,950	2.29	4.12	
	59,700	2.32	4.18			50,700	2.36	4.12	
	52,390	2.32	4.10			49,580	2.35	4.12	
	66,510	2.36	4.05	6,036		69,800	2.31	4.12	

TABLE II—CONTINUED

% Absorption.	Max. Load lbs.	B ins.	L ins.	Average Crushing Strength lbs. per squ. inch	% Absorption.	Max. Load lbs.	B ins.	L ins.	Average Crushing Strength lbs. per squ. inch
4-5	51,100	2.30	4.30			47,430	2.37	4.20	
	49,480	2.34	4.25			43,580	2.38	4.30	
	54,070	2.22	4.20			40,380	2.35	3.70	
	50,150	2.26	4.20		9-10	41,680	2.32	4.15	
	57,750	2.28	4.15			52,170	2.27	4.10	
	51,130	2.30	4.20	5,653		50,790	2.32	4.10	
	70,150	2.20	4.22			46,020	2.29	4.15	
	49,640	2.24	4.15			53,600	2.38	4.10	
	62,150	2.28	4.10			50,820	2.39	4.20	4,836
	42,150	2.20	4.30			46,630	2.37	4.20	
5-6	59,610	2.24	4.10			50,310	2.35	4.15	
	49,606	2.26	4.00			45,840	2.37	4.10	
	52,610	2.28	4.02	5,837		46,530	2.36	4.20	
	43,920	2.26	4.00			42,770	2.35	4.05	
	48,260	2.30	4.05			35,180	2.34	4.20	
	61,050	2.30	3.90		10-11	39,780	2.41	4.10	
6-7	71,900	2.32	4.15			48,950	2.41	4.20	
	62,000	2.32	4.10			47,600	2.39	4.00	
	55,370	2.35	4.05			39,140	2.37	4.25	
	66,860	2.35	4.30			36,750	2.39	4.15	4,086
	69,590	2.34	4.12			48,100	2.34	4.14	
	70,110	2.31	4.20			38,370	2.37	4.00	
	66,100	2.25	4.17	6,418		35,530	2.38	4.10	
	61,320	2.31	4.09			40,650	2.33	4.10	
	50,660	2.32	4.22			26,440	2.38	4.10	
	63,750	2.29	4.17			41,500	2.38	4.12	
	49,410	2.25	3.88			38,260	2.35	4.15	
	45,150	2.29	4.06		11-12	39,850	2.38	4.20	
7-8	67,630	2.33	4.16			37,700	2.40	4.15	
	37,030	2.36	4.11			44,960	2.39	4.32	
	59,370	2.30	3.80			41,490	2.36	4.30	
	50,180	2.39	3.97			44,680	2.37	4.20	
	44,290	2.30	4.21			37,150	2.33	4.25	3,973
	47,650	2.32	4.14	5,354		34,580	2.34	4.12	
	56,500	2.35	4.01			33,580	2.37	4.15	
	42,630	2.35	4.10			38,000	2.38	4.15	
	48,850	2.30	4.25			42,230	2.37	4.10	
	49,200	2.36	4.26			41,380	2.38	4.12	
	57,100	2.29	4.05			36,940	2.39	4.15	
	51,850	2.35	4.05		12-13	34,090	2.42	4.24	
8-9	47,470	2.34	4.28			30,890	2.41	4.10	
	35,920	2.34	4.14			33,640	2.37	4.15	
	49,790	2.40	4.15			31,820	2.36	4.20	
	49,650	2.40	4.13			32,650	2.38	4.25	3,330
	52,290	2.32	4.03			26,400	2.41	4.20	
	50,510	2.33	4.10	4,768		33,890	2.38	4.20	
	50,120	2.40	4.05			34,850	2.42	4.10	
	48,160	2.37	3.90			34,950	2.39	4.15	
	38,540	2.37	4.22			28,730	2.30	4.05	

TABLE II—Continued.

% Absorption.	Max. Load lbs.	B ins.	L ins.	Average Crushing strength lbs per squ. inch	% Absorption.	Max. Load lbs.	B ins.	L ins.	Average Crushing Strength lbs. per squ. inch
	43,950	2.37	4.22			20,460	2.41	4.16	
	32,540	2.44	4.20		15-16	14,160	2.40	4.18	
13-14	26,630	2.42	4.20			19,060	2.45	4.26	
	31,750	2.42	4.18			25,650	2.41	4.20	
	26,710	2.36	4.00			18,250	2.42	4.12	
	24,910	2.46	4.20			25,280	2.40	4.15	
	24,950	2.34	4.20			18,270	2.42	4.00	2,030
	22,170	2.42	4.15	2,494		20,270	2.41	4.25	
	20,970	2.43	4.30			18,500	2.46	4.30	
	23,930	2.35	4.28			20,510	2.43	4.20	
	31,140	2.42	4.23			21,550	2.36	4.15	
	24,320	2.40	4.35			23,000	2.28	4.12	
	26,210	2.43	4.26			19,870	2.36	4.30	
	20,060	2.45	4.20		16-17	15,100	2.43	4.18	
14-15	28,130	2.43	4.25			16,900	2.43	4.18	
	26,720	2.47	4.20			13,060	2.44	4.24	
	22,000	2.44	4.10			16,240	2.48	4.50	
	27,840	2.44	4.20			17,640	2.45	4.10	
	25,120	2.47	4.20	2,419		17,960	2.47	4.20	1,483
	23,490	2.43	4.30			15,840	2.41	4.56	
	26,350	2.46	4.26			11,300	2.46	4.20	
	24,480	2.44	4.33			10,070	2.49	4.28	
	23,610	2.49	4.13			19,300	2.45	4.20	
	23,280	2.39	4.22			15,750	2.40	4.25	
	27,550	2.39	4.28			15,490	2.43	4.10	

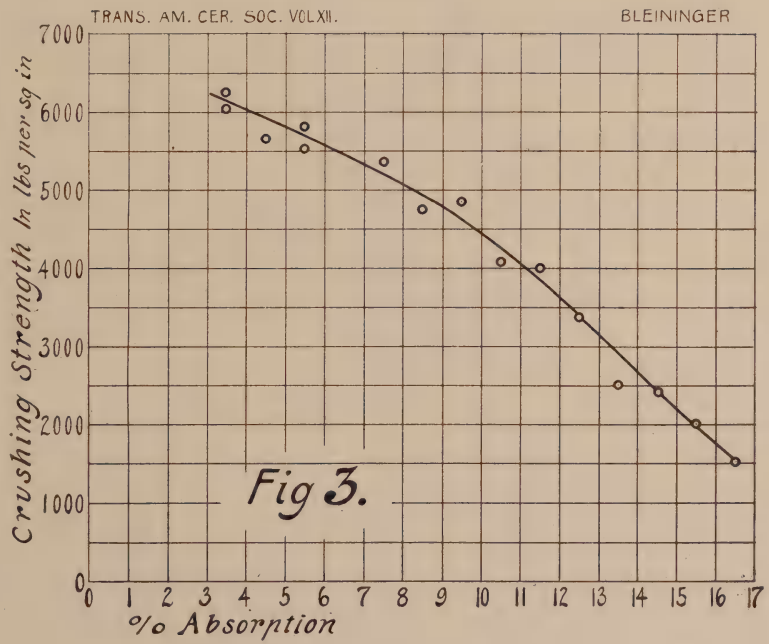
Brief consideration, however, will show that this relation cannot be true for any individual clay where the inherent strength increases as the porosity decreases, and while in the composite curve shown it happens that the resultant strength is roughly a linear function of the absorption, this is more or less a coincidence. The compressive strength curve cannot, in the nature of the case, be a straight line, but must be a higher function of the porosity.

B. In this series of 140 crushing strength and absorption determinations made from the same shale mixture, the relation between the two factors is shown more clearly and, of course, the results are applicable only to this one material. One of the principal objects in making these tests was to determine the number of individual tests required to produce comparable averages, since it was re-

alized that single, duplicate and even triplicate tests are of no value in bringing out general effects. It was found that while ten tests suffice to plot a point and give a curve showing reasonable coordination, probably fifteen should be used in order to merge the inevitable differences due to structure variations into representative values.

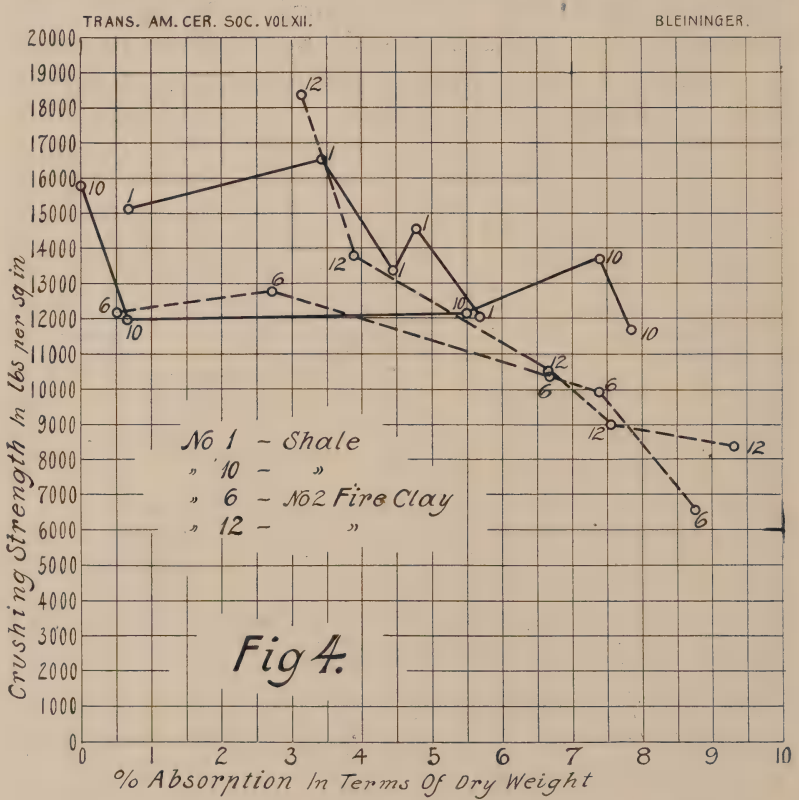
This point is readily appreciated by observing the figures obtained in these tests compiled in Table II. The compression tests again were made on half bricks, on edge.

The curve of Fig. 3 presents the average relations between strength and absorption. It is evident that the

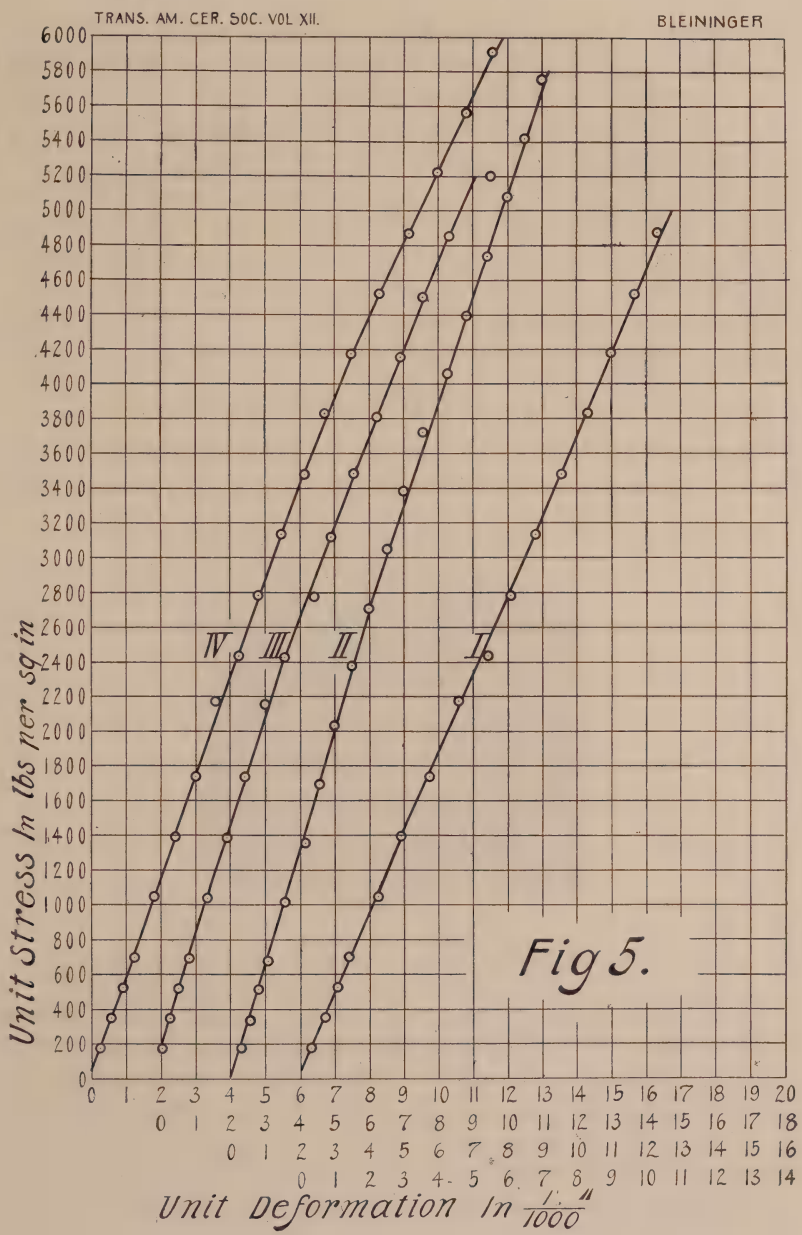


high part of the curve is lacking since none of the bricks showed an absorption of less than 3%. It is an interesting fact that the strength is considerably lower than that shown by the composite curve, Fig. 2, from the highest absorption down to 10%, while from 10% to 4% the two

curves are practically identical. Expressed mathematically by means of an empirical formula, and substituting the constants in the equation $y = a + bx + cx^2$, we find that $a = 6400$, $b = -38.75$ and $c = -16.25$, y representing the crushing strength in pounds per square inch and x the per cent of water absorption, by weight. It is evident that these constants hold only for the curve as far as drawn,


TRANS. AM. CER. SOC. VOL XII.
BLEININGER.
Crushing Strength in lbs per sq in
% Absorption In Terms Of Dry Weight
No 1 - Shale
" 10 - "
" 6 - No2 Fire Clay
" 12 - "
Fig 4.

and do not apply to lower absorptions than those shown, the function of the completely vitrified strength not being known. The equation, $y = 6400 - 38.75x - 16.25x^2$, thus enables one to calculate the average crushing strength of these bricks, knowing the per cent absorption.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER
Unit Stress in lbs per sq in
Unit Deformation In 1/1000"
IV
III
II
I
Fig 5.

Similar formula could be calculated for any other set of bricks, and would hold as long as the clay mixture and method of manufacture are the same.

C. Fig. 4 represents the results obtained in testing cylinders 3⅛ inches in diameter and 7⅛ inches high, made on an auger machine and using a dry die. These specimens were made from four clays, two shales and two No. 2 fire clays, five cylinders having been tested for each absorption, or 100 tests in all. It is evident that this number is not sufficient to produce average results. At the same time, auger structure defects manifested themselves, which proved to be more serious than was at first anticipated. From the curves of Fig. 4 it is observed that the No. 2 fire clays proved to be more uniform in behavior, though their strength at lower absorptions appears to decrease some-

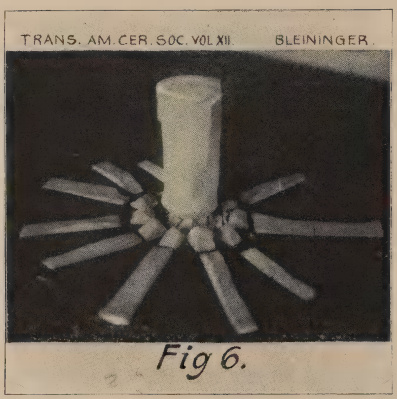


Fig 6.

what more rapidly than that of the shales. That these tests, in spite of the sharp failing points due to the cylindrical shape, are of little value is further illustrated by the elastic modulus curves shown on Fig. 5, which represent cylinders of the same clay and the same absorption. The curves, it is observed, start from different origins to avoid confusion, and should be compared for parallelism and

elastic limit. It is evident that they are not parallel and that the elastic limits differ. This must be attributed to structural defects, which are illustrated in Figs. 6 and 7. In Fig. 6 we have a case showing the difference in density between the interior and the exterior of the cylinder. As th load approached a certain point the outside of the cylinder broke with an explosive noise and snapped off in regular pieces, leaving virtually a fairly symmetrical polygon. It is evident that such a test is erroneous, owing to the decreased area on going to complete failure. The density of the outside is unquestionably greater, a condition inherent in the flow of clay through the die and which is neces-

Fig 7.

sarily accentuated in burning to a good hardness, so that a latent strain is practically unavoidable in pieces of this character. The use of a lubricated die would have lessened this difficulty undoubtedly.

The common auger structure is shown in Fig. 7, which is so evident that no explanation is necessary.

For the reasons stated, the results on the 4 and 6 inch cylinders are not reported.

Summary.

The importance of having specifications for bricks is pointed out.

It is important that the half bricks be tested on edge so as to remove a source of large error. No reasonable ratio exists between bricks tested flat and those on edge, excepting for the same brand. The results of 176 brick tests are given.

It is found that in correlating compressive strength with absorption two curves exist. One approaches a straight line and expresses the relation down to a certain absorption, which approached 3 or 4 per cent. The other has a decidedly more rapid slope and is a more complex function. Both decrease in porosity and gain in inherent strength govern these relations.

Not less than ten tests should be made of the same grade of the brick, and fifteen should be more desirable if it is desired to bring out the average relation between absorption or porosity and crushing strength.

For the same product down to where vitrification begins to become more evident, it is possible to calculate the compressive strength from the absorption and without doubt also from the porosity, sufficiently accurate for practical purposes.

The effect of structure is very prominent, and must be carefully guarded against in accurate investigations.

Repressing has a tendency to lower the compressive strength.

DISCUSSION.

Mr. Douty: I had no intention of taking part in the meeting, but I have had some experience in the crushing

tests on brick and I agree with Professor Bleininger. The crushing test of any specimen in which the dimensions along the axis of application of load is less than the cross-dimensions, will give an exaggerated value, and the variation in results and the irregularity of the fracture, is due to the improper proportioning of the prism as well as to lack of homogeneity in the material. The specimen after a true break would give inverted cones. As you shorten the dimension in the direction of the force the solid angle of the cone becomes greater, the stresses are distributed unequally, the fracture becomes irregularly columnar and will take place in varying directions as stated. I think that the wide values which you get for any particular sample is due very largely to non-uniform distribution of the shearing stresses. Professor Bleininger has spoken of the common objection that is made to the testing of the brick on edge or on end, in that the brick is not subjected in use to pressure in that direction. The brick in the wall is not subject to a single force in one direction. It is laid in a composite form, subject to the bonding of the mortar, and I do not think that the objection holds. I think you will get better and more uniform values if you test the prism whose height, in the direction of the compressive force, is at least one and one-half to twice the cross-dimensions of the specimen.

I would suggest that this rule is really derived from the testing of metals where your material is homogeneous. If you take a piece of steel and test it with your load in the direction of the short dimension, you will get a very much higher value than you will if the pressure is properly applied in the direction of the long dimension. That was worked out very nicely by Bach and is very ably discussed and beautifully illustrated in his splendid work "Elasticitat und Festigkut."

Mr. Ries: Mr. Bleininger, do I understand you to say that repressing any kind of bricks reduces their crushing strength?

Mr. Bleininger: I must say that the bricks tested were stiff mud brick, and I do not want to include soft mud brick in this classification.

Mr. Ries: I think that in soft-mud brick repressing increases their strength considerably.

Mr. Richardson: Did you notice any difference between the side-cut and the end-cut brick?

Mr. Bleininger: Not so much a difference in the ultimate strength as a difference in the direction of greatest strength. Some of the end-cut brick were stronger when tested on edge than when subjected to the load in the flat condition. Most of the side-cut bricks showed the opposite to be the case.

REQUISITE PROPERTIES OF GLASS FOR MECHANICAL MANIPULATION.

BY

R. L. FRINK, Lancaster, Ohio.

There is much discussion among workmen and tradesmen in the glass industry as to the causes of the various imperfections of glass, and the reasons for the losses by breakage, shivering, checking, etc. One hears warm arguments among the men over these topics, but the fruits of these arguments seldom find their way into technical literature, nor have the reasons for the above troubles been explained in a wholly satisfactory manner.

Since the advent of the machine manipulation of glass for the manufacture of sundry articles, including sheet glass of various kinds, these reasons have become more and more urgently sought. Manufacturers, superintendents and wokmen are rapidly coming to recognize that some better method than guess work must be found to deal with these difficulties. There are now several manufacturers who are devoting more or less study to the scientific side of glass making.

In manipulating glass mechanically, there are beside the question of machine design, four essential factors upon which economical production and satisfactory quality must rest, viz.:

(1) Homogeneity of the metal or fluid glass.
(2) Viscosity.
(3) Temperature.
(4) Density.

It will probably be well to define somewhat particularly what is meant by these terms, and explain how they affect the economy of the process and quality of the output.

Homogeneity of Metal. Perfect homogeneity in a body of metal implies the complete solution of all the ingredients, one in the other and the mixture of the bath until all parts of the metal are alike, physically and chemically. A glass in this condition, if cut and polished and placed between crossed nicol prisms, or viewed by polarized light, should show no striae nor indication of lamination.

Viscosity. By viscosity is meant the degree of fluidity of the metal. The more perfect the fluid, the more rapidly will it take the shape of a containing vessel, the more perfectly will its upper surface maintain the horizontal, and the more rapidly, all other things being equal, will it escape through an aperture of given cross section.

In applying this conception to fluid glass or "metal," as it is called in glass works, it has been necessary for the writer to devise some mode of comparison of the viscosity of different glasses. The following has been found convenient:

If an orifice 100 millimeters long by 3 millimeters wide be made in the bottom of a receptacle filled with molten glass at 1000°C, under a pressure of 100 millimeters of mercury, there will flow through this orifice a stream of glass varying in width with the viscosity. The higher the viscosity, the wider the stream. If the viscosity of the fluid be 100, none will escape.

In the case of an ordinary window glass, let us suppose that the glass will flow out in a ribbon having a width of 80 millimeters. In the case of a lead glass, under conditions equal in all respects, let us suppose that a ribbon 60 millimeters wide is found, the respective viscosities of these two glasses are then expressed at 80 and 60 respectively, being the relation of the width of the stream of glass, measured where it has attained a constant cross-section, to the width of the orifice.

It is not to be supposed that the weights of the amounts of the two glasses are in the ratio of 80 and 60, for the two glasses are of different composition and differ-

ent molecular weight, and hence cannot be compared very intelligently in this respect. For instance, 340 grams of the window glass might flow per minute in the first case, while 600 grams of the lead glass might flow in the second, in a narrower stream but with higher rapidity of flow.

The viscosity is directly affected by the temperature of the glass. In general, the higher the temperature the lower the viscosity, i. e., the thinner and more watery the fluid. If we were to reduce the temperature in the above instance from 1000°C to 900°C, the viscosities would change; the window glass might now flow a stream 90 m. m. wide, and weighing 200 grams per minute, and the lead glass might flow 90 m. m. wide but with 500 grams flowing per minute. It is, therefore, necessary in speaking of the relative viscosity of glasses to specify the temperature, as well as the width of flow through an aperture of standard shape.

The writer has used this empirical method of obtaining expressions for viscosity in studying the relative qualities of salt cake glass vs. soda ash glass of the same chemical compositions. No attempt has yet been made to formulate any more exact expressions, but the writer believes that it is possible to design an apparatus embodying this principle from which definite values could be obtained, which would enable the physical properties of the glass to be forecasted, and conclusions reached as to its fitness for any special purpose.

Temperature. The temperature of a fluid glass vitally influences its viscosity and therefore, since the degree of viscosity necessary for glass to work well in any given machine is approximately a fixed quantity, it follows that for the same glass there is a critical or specific temperature at which it must be worked, if the best results are to be attained.

Density. The density of the glass is also an expression for the perfectness of the fusion. In a perfect fusion, the gases set free in the metal fully escape, and at working

viscosity, the glass is free from blebs of gas or bubbles. Its density is, under those conditions, a function of its chemical composition. A lead glass would outweigh a lime glass, by reason of its chemical constituents. But if the temperature is too low, the glass may be "seedy" or "blebbed" and its apparent density will be lowered by the inclosure of bubbles within the mass, which cannot escape on weighing. The true density or specific gravity, determined by pycnometer on the crushed and powdered glass, should show little variation except those due to variation in proportion of constituents.

It is obvious that the control of the quality of the output of a glass plant involves the control of these factors. Homogeneity is necessary, because if the glass is of different chemical and physical properties in different parts of the metal, then a striated or laminated product will result which can be detected by eye if the article is of such character as to transmit light freely.

Control of viscosity is necessary, because if the glass is too viscous or rather, if the viscosity varies materially when manipulated mechanically, it becomes very difficult to adjust the mechanical manipulation with the varying rates of flow of glass to the machine.

Control of temperature is necessary, because neither homogeneity nor viscosity can be controlled without controlling the temperature, though the temperature alone is in excess of that necessary to secure reasonable fluidity is dangerous, giving rise to blisters, burns, scale marks, and other defects. Temperature below the right point means too slow a flow to secure mechanical manipulation, resulting in imperfectly filled molds. The apparent and the real density must also be substantially equal, because difference indicates a bubbled structure and therefore improper melting or firing.

The manipulation of glass by mechanical means should be, and is a comparatively simple operation because its physical properties give us every possible advantage for

doing with it as we will. It passes through all the transitory stages from solid to liquid, and is either of these in any required degree, according as the four heretofore-named factors vary, one to the other.

Many a mechanical device has been built, on which much money and labor has been expended, and which, so far as mechanical design was concerned, has operated without fault, but when the glass was applied has failed to produce the finished article in required quantity and of saleable quality. It has usually been set aside as the monument of a "foolish ambition," or at once relegated to the scrap heap, when really it might have been made a complete success by application of the proper metal, or by the adjustment of the physical properties of the glass, and the kind and amount of manipulation.

To cite an instance—the writer but a few years ago was asked to witness the operation of a blowing and pressing machine, which had been giving a great deal of trouble, and on which there had been spent several thousand dollars, but which nevertheless defied all attempts to continuously produce a sufficient output of the required commercial quality, to make the machine economical, or give it any advantage over the usual method of manufacture.

The glass used was of the composition usually found in rough pressed ware, although subsequent analysis determined it to be a little higher than the average in alumina content, carrying approximately two percent of this material.

It was found that the glass was put into the machine at about 1040 degrees C., but at this temperature the molds could not be made to fill. The glass thus did not take the impression of the design nor form the edges as perfectly as required; further, there was considerable tail-mark, and lamination, or cord, in the finished piece. The temperature of the glass was raised, producing lower viscosity. While this mitigated the difficulty to some extent, when the viscosity was brought to the point where the mold would fill to an approximately satisfactory degree, the mold would

"burn" in the sharp corners or edges exposed. In addition the tail mark was still left, and could not be made to disappear.

Then the glass temperature was lowered, and the molds were heated to approximately 320 degrees C. This assisted in filling the molds, and giving better edges, yet it did not do away with the tail mark, nor did it lessen the oxidation of the sharper edges of the mold.

After numerous experiments, and considerable additional expenditure of time and money, the owners had about decided that it was the fault of the machine and its design. When a question was asked as to how the machine could cause this difficulty, or what specific thing it was in the machine which produced these conditions or where it differed in its action over the two-operation, or perhaps three-operation, manipulation, to which the piece was subjected when made by the ordinary hand method, no one could seem to offer a satisfactory, logical or reasonable explanation.

It was therefore suggested that the machine be taken into a factory where a different glass was being made. As a consequence, it was tried on a pot of very soft opal glass, whose soda content was exceedingly high, approximately 18%, but which likewise carried a very high alumina content, about 4½%, the opal color being produced by the use of alumina and calcium phosphate. When the machine was tried on this glass, no difficulty was experienced whatever in completely eliminating the tail mark, nor in obtaining perfect edges.

The mold filled nicely, and the article received the impression of every discernable configuration of the mold.

The machine was then tried on a pot of glass, made up at the suggestion of the writer especially for this experiment, analyzing as follows:

Silica, SiO_2	63.00
Calcium Oxide, CaO	11.60
Magnesium Oxide, MgO	5.75

Barium Oxide, BaO	3.43
Potassium Oxide, K_2O	3.00
Sodium Oxide, Na_2O	11.43
Iron, Alumina } Fe_2O_3, Al_2O_3	2.50
	100.71

This glass was charged and melted in the usual manner, in an ordinary flint pot, and after a little difficulty in "planing" the pot, it was gathered and put into the machine, with the result that almost perfect operation was secured. The product coming from the machine showed substantially a perfect reproduction of the mold configuration, with clean sharp edges, and little if any tail-marking could be found. The temperature of the glass was maintained at about 1100 degrees Centigrade, and that of the molds at about 220 degrees C., which is the ordinary figure.

This machine, or its descendant, has since that time been used quite extensively in the manufacture of various articles and in the making of lamp chimneys, but whether the last given formula for the glass was finally adopted, the writer cannot state. This is one of the several instances in which the writer has had an opportunity to assist in determining and overcoming some of the difficulties attending the manipulation of glass by mechanical means, and in nearly every instance it was found that the properties of the glass itself contributed largely to the perfect and uninterrupted production of ware of the proper quality and quantity.

Another instance where a somewhat similar condition existed was in the making of flat opal plates to be used for facing brick. It was necessary that these plates should be accurate in measurement with a perfect smooth surface, and should show no tail marks, checks, or warping. It was also necessary that the glass must have annealing properties which would permit it to withstand considerable changes of temperature, and possess rather high tenacity.

At first the usual opal glass was tried, the same being made in a day tank, but with no success. Nearly all of

the above mentioned imperfections were present, to say nothing about a 15 per cent breakage, which occurred after leaving the lehrs.

The molds were then taken to a factory where they made their opal glass in pots, but a like result was obtained. Another manufacturer was tried, and again there was a failure, when finally, in desperation, a small experimental furnace was built, and an opal mixture was tried which contained some lead, but with no improvement other than that there was not quite so pronounced a tail mark as in the previous trials. A batch was then made up of about the following proportions:

Sand	100
Soda	35
Lime	4
Fluor Spar	22
Feldspar	30
Niter	4
Borax	2
Barium Carbonate	6
Manganese	0.125

Unfortunately, no analysis of this glass was made after the same was melted and worked, but the results obtained were surprisingly satisfactory, as little or no warping occurred, checks were something very rare, the color held without any difficulty, and tail marks were usually absent. Several thousand pieces were made from this batch and gave entire satisfaction for this particular work, again demonstrating that the physical properties of the molten glass are a determinig factor in the manufacture of the product by machine.

Let us consider wherein the four factors above enumerated enter into, and have any bearing on, the two instances cited. It is to be regretted that full data were not secured, so that a more perfect knowledge could be obtained of the effect of the increase or decrease of the various constituents in the batch mixture.

In the first instance it was found that glass of ordi-

nary composition was entirely too viscous at the usual working temperature, and could not be made to flow through the mold in the length of time required for the operation, before it would chill to an extent such as to prevent it from "filling" the mold perfectly. Also on allowing the lump of glass to drop from the gathering rod by its own gravity it would, because of this high viscosity, produce a heavy tail. This tail when sheared off, would enter the main body of the metal in the mold, but its viscosity as too great and it could not be assimilated and made homogeneous with the balance of the metal because there was not a sufficient excess of heat in the main mass to reheat this heavy tail portion to the point of perfect physical union.

Now in the special glass, which made the machine a success, a higher soda content was used which made the glass more fluid, or of lower viscosity, and, therefore, at its working temperature only a very small tail was produced at the speed at which this machine was then being operated. When this glass was gathered on a punty iron, and allowed to drop into the mold and sheared, it was sufficiently liquid, even at a lower temperature, to permit the tail settling at once into the main body of the metal, absorbing heat therefrom, and immediately becoming assimilated. Further, when the plunger came in contact with it, the metal would flow further before cooling than in the previous instance, and, consequently, took the mold configuration. This, however, was controlled to a great extent by the speed of manipulation.

In the second instance cited, a similar condition existed, only that here it was necessary to have a glass with high elasticity in order that warping of the flat plate should not ensue, and here is where the borax and barium oxide play an important part, although perhaps zinc would have been still better. So far as the tail marks were concerned, the same results were obtained as in the first instance by the use of the high soda, as the effect produced

by barium oxide (BaO) greatly resembles that of sodium oxide (Na_2O). However, barium has the property of giving greater viscosity than soda, but this was counteracted to a considerable extent by the addition of borax and saltpetre.

In the manufacture of plate glass, the first, third and fourth factors are the most important. Viscosity, in the casting of a plate of glass, is but a small factor, inasmuch as the glass is melted in pots of great size, which holds the required quantity of glass for the making of a plate of large dimensions, and the total contents poured upon the casting table in the space of a few seconds, and rolled out, between guides, by a roller, into a sheet of standard thickness. There is but little opportunity for the viscosity of the metal to change by cooling or have any effect under the enormous weight of the advancing roll.

The temperature is of the first importance. The metal must be subjected to a proper degree of heat in order to obtain thorough melting of the ingredients; it must be maintained at a proper temperature in order that all of the gases may be liberated and the metal be sufficiently fluid to permit their escape.

The manner of charging raw materials into the pots, and the temperatures throughout the melting period, to a considerable extent control the homogeneity of the metal. It has been found that if a slow fire be used, and a pot of glass melted under these conditions be drained too closely, there will be formed in the plate what is called a "ream." In the opinion of the writer this is due to the soda fusing first, and settling to the bottom of the pot giving the bottom layers of glass a greater fluidity than the glass above it. This invariably occurs to a more or less extent, if the pot be drained too closely, this high soda glass being cast in the plate. This is not only detrimental to the final quality of the product, as high soda glass resists weather less perfectly, but it is also injurious because of the impossibility of perfectly annealing an unhomogeneous

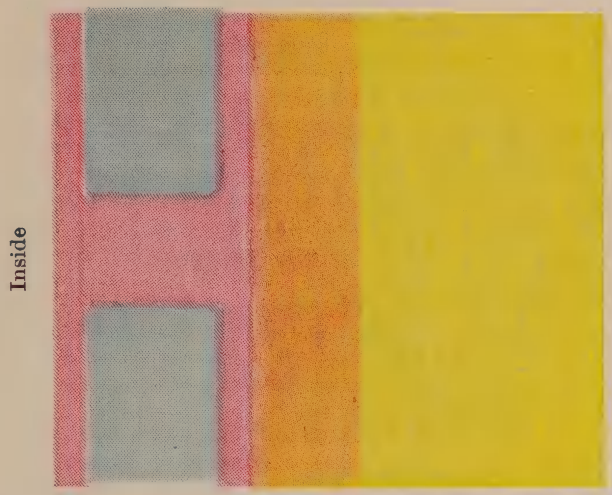


FIG. I. Transverse Cut

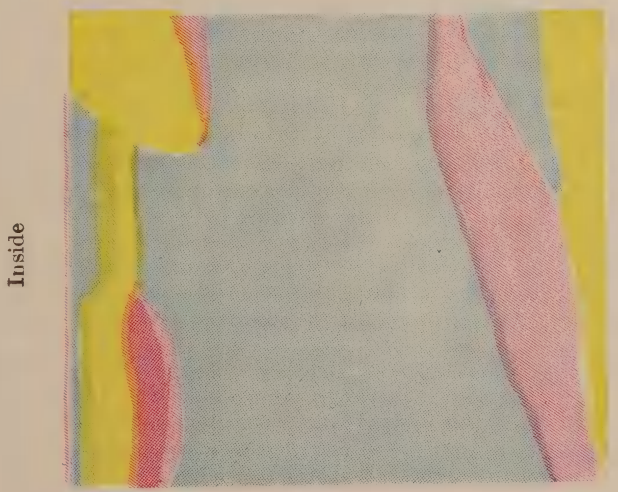


FIG. II. Longitudinal Cut

sheet. Strains will exist if the glass is chemically unhomogeneous and, as a result, the breakage is greatly increased.

Probably there is no place where all four factors so vitally affect quantity and quality as in the production of sheet glass by the various blowing machines. The writer believes that if one can thoroughly understand and determine the exact relation of these four factors to each other, and govern this relation perfectly, the production of sheet glass would be one of the simplest and cheapest industrial processes in the country.

Assume that a cylinder is being drawn from the bath of glass, the temperature of which is 1120° C., and that this glass has been taken from the tank furnace by means of a ladle, or dipper, which has reached below the surface of the glass 9 inches, or in other words, has taken up metal 9 inches deep. This has been poured into a vessel, or pot, and a cylinder is being drawn up from the surface at a rate which will produce at hickness in the cylinder walls of one-eighth of an inch.

As stated, the temperature of the glass ladled into the pot is 1120°C. The temperature of the glass decreases 2 degrees C. per inch in depth after the first ladling, so that there is a difference of practically 18 degrees between the lower stratum and the surface taken up by the ladle. At the end of the fourth second after pouring of the glass in the pot, the temperature ⅛ of an inch below the surface is 960°C.; at the end of the first minute it is 935°, and at the end of the second minute it is 915°. Now the temperature at the surface of the glass at the end of the fourth second is 860°; at the end of 30 seconds it is 840°, and remains 840° throughout the drawing operation for a period of 9½ minutes, or so long as there is a body of glass below the surface, of which the temperature is greater than 900°, there will be a temperature maintained at surface of 840°, which is the point of balance between the conductivity of the metal and its radiating capacity.

The vessel from which the glass is being drawn has a diameter of 28 inches and the cylinder a diameter of 14 inches. Therefore, the surface of the glass outside of the 14-inch cylinder is radiating heat to the open air, while inside of the cylinder, the surface is protected. The surface temperature outside of the cylinder wall would be 840°C. and on the inside 960°. Therefore, the viscosity of the metal on the exterior of the cylinder is constantly greater than that of the metal on the inside, and if the speed at which this surface is removed is such as to maintain a temperature of 960° one-quarter of an inch below the surface and 840° at the surface outside of the cylinder walls, and the viscosity of the glass measured as described earlier, is 78%, we will have obtained a cylinder 14 inches in diameter and walls ⅛ inch in thickness, providing we have a glass whose homogeneity is good.

Now let us assume that the point "A" in the mass of glass represents a portion of the lower stratum of 9 inches of metal which has been taken from the tank, or in other words, that 9 inches below the surface there has come down a glass whose viscosity is greater than that at the surface. There will therefore be formed in the walls of the cylinder a thickened portion called a "cord," and this will destroy this portion for first quality.

If a section be cut from this cylinder, transverse to the axis of the cylinder, and viewed by means of polarized light, interposing a selenite plate, we will find a color display similar to that shown in Fig. I. Fig. II shows a longitudinal section, cut from the edge of the cord.

The variation in the viscosity of the metal and the cords produced in drawing the same have disqualified this portion of the glass for commercial use, and in the production of this machine at the date of this record, there was a breakage averaging 87.6%, which is almost beyond belief.

In this case we have a clear example of non-homogeneity, for it was found by analyses that the glass thoughout this cord varied considerably from that surrounding it.

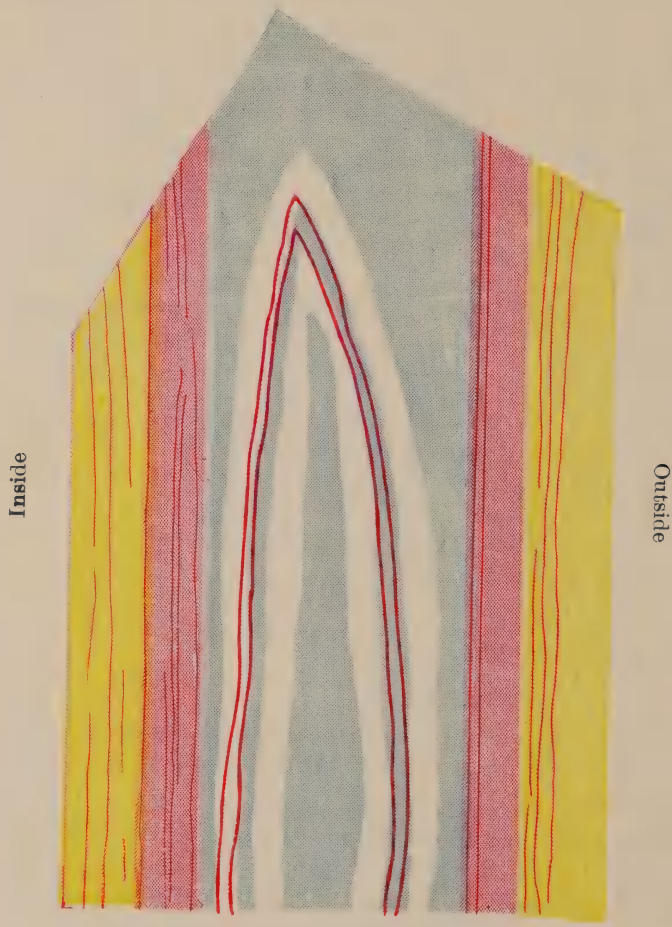


FIG. III. Transverse Cut

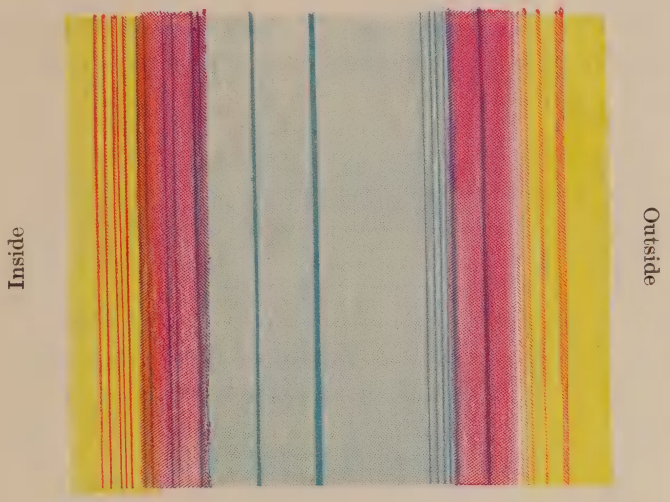


FIG. IV. Transverse Cut

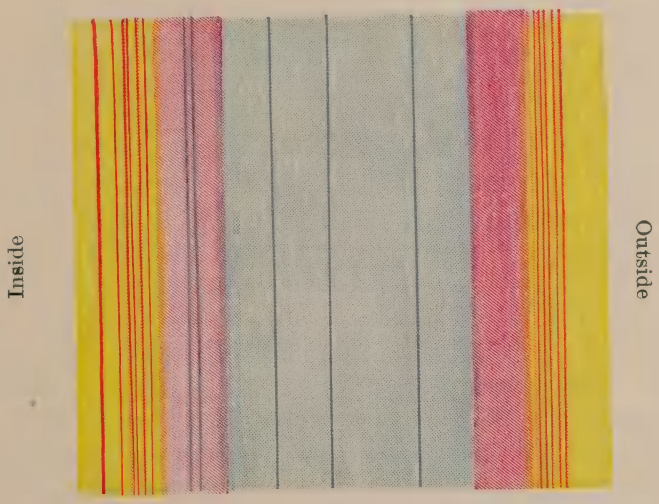


FIG. IV. Longitudinal Cut

In Fig. III, however, we show another example of non-homogeneity. In this case, the breakage averaged 83.2%.

Another example of non-homogeneity is seen in Fig. IV. It will be seen that here the lack of homogeneity is due to a stratification of the metal. The breakage under these conditions, as shown by our record, was 78.3%.

In following up these studies it was found that when these lines did not appear, and practically no striae were apparent, the furnace conditions were, and had been, very constant for a considerable period of time. An example of what might be called normal glass produced under uniform furnace conditions is shown in Fig. V, in which the breakage is but 3.2%. On the day previous to that we had a breakage of 7.2%, and in the Plate VI an increase of striae will be seen.

In all of the illustrations, the coloring is due to the introduction of a selenite plate, or red of the first order. All sections are magnified about twenty-five times, the reproductions being taken by means of a B. & L. petrographic microscope, using 1½ inch objective and 2 inch ocular, and a B. & L. camera lucida. The outside and inside stratum of the rollers appear as yellow, with an intermediate stratum which approaches more or less nearly the color of the field as it would appear if there was not any glass, or other substance, in the path of the light ray.

It is assumed by many that the outside surface of a sheet of glass, or any glass article, is under a tension. If a specimen be placed under the microscope, between crossnicols, with the selenite plate, or red of the first order, between the ocular and the objective, and with the zero mark at the front of the microscope the specimen being in line with the 45 degree and 225 degree graduation, the outer and inner stratum of the specimen will appear as yellow, and this shows a compression strain at right angles to the axis of observation. This fact may be readily veri-

fied by taking a piece of glass which introduces no light interference or depolarizing properties, and by compressing it between the jaws of a pair of pliers, or other means, it will give the same yellow appearance.

The entire rationality of expecting to find compression will be obvious by giving the matter a little consideration, for when the sheet of glass is made, the outer surface cools first, and then the inner surface cools, the center stratum remaining a little longer in a more or less viscous condition. This mass in contracting during the cooling period, must of necessity produce a crushing strain on the surface strata which first set, while the inner stratum which solidified free of strain will now be placed in tension. There must also of necessity be two other points between the tension and compression strata which will be neutral; therefore with a specimen placed at the angles and under the conditions above stated, the center will appear blue, and as will be seen, there will be two lines which will approach to a more or less degree the neutral. These colors vary in depth and degree from the red, as the strains are more or less intense.

Of course wherever there is a lack of homogeneity in metal, much breakage and loss can be avoided by proper regulation of the temperature and annealing conditions. In speaking of temperature, I mean the entire temperature treatment as applied to the making of a piece of glass from the time the raw materials enter the furnace until it has passed beyond all stages of heat treatment. As all glass manufacturers know, there is much breakage occurring in their factories, which it attributed by them to many causes, but chiefly is placed at the door of the workman. However, the writer makes bold to state that in his opinion, if the glass is properly constituted and melted, it is beyond the power of any workman to make that piece of glass so that it can or will "blow up" after the article has been produced.

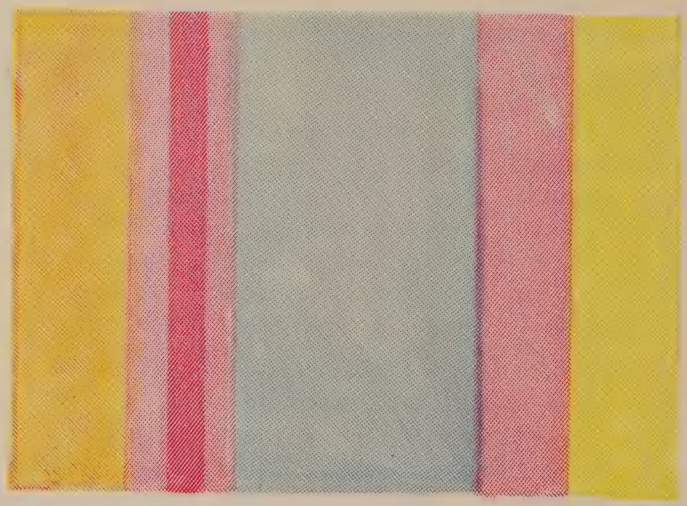


FIG. V. Transverse Cut

FIG. V. Longitudinal Cut

FIG. VI. Transverse Cut

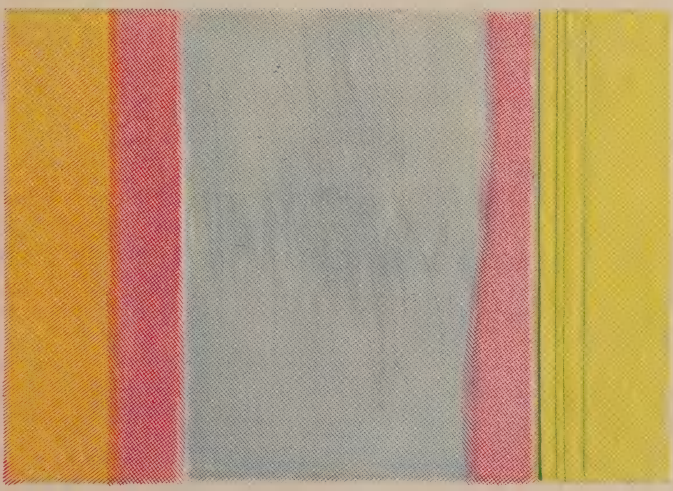


FIG. VI. Longitudinal Cut

Numerous attempts to make articles irregular in shape and form from glass when in the condition represented by Fig. V have been witnessed. If one of these articles has ever left the blower's pipe, it would invariably pass through abnormal rough handling and come out safe and whole, while on the other hand, if the condition of the glass were such as appears in Fig. IV and VI, considerable difficulty would be experienced in getting any irregular shape to pass safely through the lehr. In making this statement it is of course understood that it is possible for a man to make a piece so heavy as to act in the fashion of a "Rupert's Drop."

It is true that some glasses have the power to withstand the varying strains introduced by the reason of this non-homogeneity to a much greater degree than others. This is due probably to increasing elasticity. Lead glass in particular shows this power.

For the production of sheet glass by machine methods, particularly that method which first makes the glass in cylindrical form, there is probably no ingredient of which the control is so essential as the alumina. If an alumina content of 4% is obtained without causing opacity, or stone, which can readily be done, a glass will be produced which is of exceptionally high viscosity, and requires a fairly high temperature treatment, both of which are desirable factors for the drawing of a cylinder from a bath of molten glass. With a high viscosity at its drawing temperature, the glass will maintain a more uniform thickness throughout the full length of the roller, and changes in air currents and atmospheric influences have a less effect than with a glass of a lower viscosity.

For the same reasons, a higher temperature is desirable, as the higher the temperature the greater the speed with which the glass can be withdrawn from the bath of molten metal if its viscosity is correct.

The relation between the temperature treatment and the viscosity in a glass carrying about 4% of alumina

(Al_2O_3) is such that when it is ladled, more temperature is retained. As a consequence, any irregular cooling or heat absorbing influences surrounding the walls of the vessel would not have as pronounced an effect as with a glass of lower initial heat.

There is one disadvantage, however, with a glass of this character, namely, that greater care is required in ladling, and in cutting off the stream from the ladle there will be produced a heavier tail portion than with a glass of a less viscosity, and the same result would follow as in the instances cited where molds were used. This would tend to produce what is known in the window glass business as "music lines" and "strings."

In order to counteract to some extent this property of high alumina glass, I have found that it is quite advantageous to use carbonate of barium in the mixture, to an extent which would produce from 1½ to 2 percent, and perhaps as high as 3 percent of barium oxide in the finished product. This gives a glass of higher refractive index, and very materially increases the tenacity, without any dimunition in viscosity.

In making the above statements, no consideration has been given to the form of soda which has been used. It may seem unreasonable but it is nevertheless true, that when salt cake is used a considerably different result is obtained than when soda ash is used, particularly in respect to the viscosity.

While making some investigations as to the cause of lines, strings and cords, and comparisons between salt cake glass vs. soda ash glass, the writer became convinced that the properties of soda ash glasses were much different from those of salt cake glasses.

The statement made by workmen that soda ash glass was of a much "softer nature" than the salt cake glass, and worked much easier, had often been heard, but little credence had been given to the idea that with the same

soda content, there was any difference in the actual physical properties of the two glasses.

However, after two or three months of careful work and investigation, and comparison of quality and quantity of product as obtained on the machine for the production of window glass, it was conclusively and undisputably demonstrated that a glass in which the soda content was supplied by means of salt cake had a higher viscosity and was more sensitive to all the conditions surrounding it, than was that made by soda ash. A fact which illustrates this is that in cylinders of the same size drawn from glass ladled at 1120° C. in both cases, there would be drawn from a bath of soda ash glass approximately 8½ pounds of metal per minute, while in salt cake glass there would be drawn from the bath over 9 pounds per minute. For this reason it is decidedly advantageous to use a salt cake glass; on the other hand, owing to its sensitiveness to chill and hardness, it is found that it is a difficult matter to keep the breakage down to a point where there remains any economic advantage in the use of salt cake. Practice and careful investigation have developed a method of furnace control which has eliminated to a great extent the causes which have produced breakage, and which, it has been shown, have been due largely to irregular furnace operation.

DISCUSSION.

Mr. Staley: Hovestadt speaks about toughening glass on both sides, cooling suddenly on either side. Isn't all glass toughened by that conduct?

Mr. Frink: No sir.

Mr. Staley: What is the difference between these, this toughened glass is simply glass that is in stress on both sides.

Mr. Frink: Yes. Take for instance Jena ware. When it was first placed on the market they plunged it in an oil bath, and that oil bath would harden it on the outside,

which gave the "Rupert drop" effect, being under severe compression on the outside, and tension on the inside. But you may stretch so that when you rupture the surface it doubles up. There is also glass made which is plunged into water causing rupture of the surface, sometimes called crackle glass.

Mr. Takahashi: This may not have a direct bearing on the paper, but I would like to ask Mr. Frink if he has found the function of magnesia in regard to the working qualities of the glass, and how much magnesia is allowable. Also whether or not magnesia is objectionable at all. I heard a man express his opinion that flint glass should have a rather high content of magnesia. In other words, for a batch of flint bottle glass is it best to use dolomitic lime stone?

Mr. Frink: The question of magnesia in glass is a mooted one, I guess, among all men. Up to within two years ago, if a man had told me I could use a dolomitic limestone in producing window glass I would have been rather inclined to tell him I was from the center of Missouri. In the last year I have seen magnesia go to 11% in a limestone and we have got A-1 glass out of it. How that was done I shall not attempt to tell you. Years ago I would have said it was impossible. I have been through a good many factories in the country where magnesia is usually considered a great detriment to the glass. In flint, mold work, I believe magnesia is of great assistance, that is in some classes of flint work. It increases the fluidity and decreases the viscosity perhaps more than any other ingredient we have, and at the same time it maintains the hardness of the glass.

As to the allowable quantity I do not know that I would care to commit myself specifically. I will put it within limit of say 2 to 10 per cent.

Mr. Takahashi: At our works we use a burnt lime in which magnesia is as high as 29%, and the lime content somewhere between 55 and 58%; and as far as I could

see we never had any trouble. In one factory an analysis of the glass showed very low magnesia content, and the breakage of ware was greater at this factory than at any other factory of the company. Although it is possible that this breakage is due to mechanical defects, I thought it might be possible that the magnesia being lower in co-efficient of expansion than the lime might help to decrease the breakage on sudden heating or cooling. In testing the ware the cold ware after annealing is plunged into hot water.

Mr. Frink: In regard to the cold water test, I do not think that is any real fair test. I do not believe that in the use of magnesia in glass there is any test that will give any real idea in regard to that, for the reason that magnesia occupies on the one end of the scale just what barium does on the density end. It is lighter and increases the fluidity where barium increases the viscosity. If you have a piece of magnesia glass with a cord such as I attempted to illustrate and that cord goes diagonally across the article and you should plunge it into the water at that point, it will break, when it would not break perhaps if you plunged it in sideways or some other way that would meet these strains in a parallel direction rather than in transverse direction.

Mr. Takahashi: This test was not made especially as a test for the effect of the magnesia, but it is a common test, to which the packing wares are subjected.

Another point I would like to ask about it whether Mr. Frink has had any trouble from too high content of soda in case of pressed ware. In one instance, from a mistake on the part of a mixer, lime was increased in a batch and as the result the glass worked better. Before that time they had some trouble about the sinking of the ware in the molds, and after this mistake was made the ware stood up very well. But after the mistake was corrected and they went back to the old batch the ware started to

sink again. I might say that the soda content in the glass was about 16 or 17%.

Mr. Frink: I think Mr. Takahashi has given a better example of viscosity and properties affecting it than I brought myself. Naturally when you increase your viscosity your stuff will stand up in your moulds better, but if you have got any configuration to attain, that is, any sharp corners to get into, too much lime will prevent this, therefore if you increase your soda you increase the fluidity, but the consequence is that you lower the softening point, and I believe that a large percentage of manufacturers are entirely too prone to use too much soda. They will make better ware, it will anneal better, it will take better shape, and be better in every respect if they will conform more closely to the silica ratio, that is, the old ratio of 5 to 1. There is an illustration of it here. You have not lime enough to keep the soda from forming a solution outside of it, you might say. I can not express it exactly. Your magnesia has not that property. It has the property of making the glass very liquid when you get a certain temperature, but as that temperature drops, your viscosity increases very rapidly. Soda does not set in this manner.

Mr. Silverman: These points Mr. Frink brought out will prove very valuable for one reason alone, and that is, that the manufacturer of glass has been in the habit of throwing soda or lime into the batch arbitrarily in cases of trouble. If the glass did not melt as quickly as he thought it should, he threw in more soda, and if the reverse condition obtained he threw in more lime. These data ought to prove conclusively, unless future counter data are shown, that there is a proportion which is just the right one, and that if this proportion does not bring about the desired results, the fault must lie outside of the batch itself.

There is one point I would like to ask about and that is the polarization test through the use of selenite plates.

Just how does Mr. Frink go about this test? Do I understand that he uses a sample which has been etched for this purpose, or does he examine a section which has been cut down and polished?

Mr. Frink: I am sorry a box did not get here that I shipped, in which I had all these samples, and also I had some samples of the chords, which would emphasize some

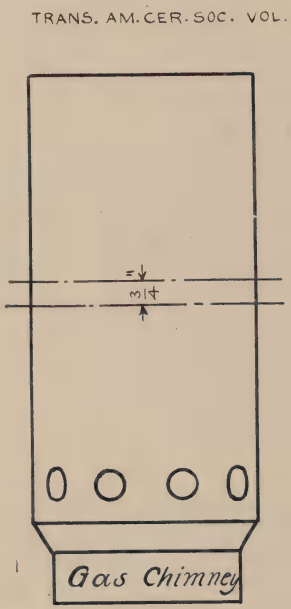


Fig. 7

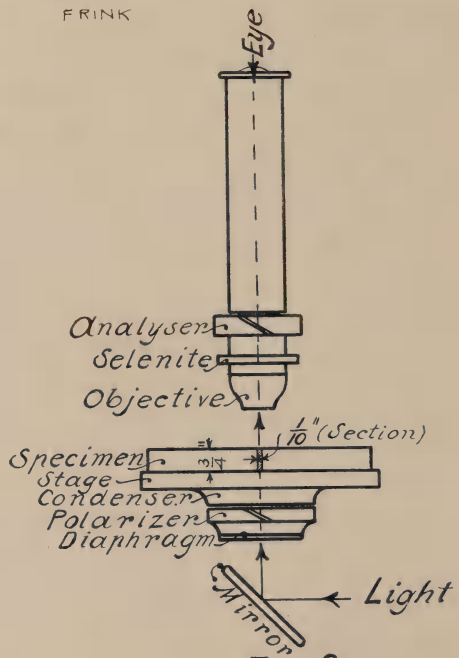


Fig. 8

of those points Mr. Takahashi has brought out. Perhaps I can illustrate it a little better on the board. This is the objective here. I introduced the selenite plate here, as shown in Fig. 8.

Mr. Silverman: Can you detect that condition in any part of the specimen?

Mr. Frink: Yes, if the condition is there, you can.

You cannot detect it unless you are looking at right angles to the axis of the strain produced.

Mr. Silverman: Do you examine the specimen at the point at which you have the trouble with breakage?

Mr. Frink: If we have had any trouble in breakage we take any specimen from a piece of glass, say a lamp chimney, (Fig. 7), or something of that kind, and cut out this section about ¾″ wide, put it under the microscope on edge as described, and if I find that general condition of lines exists, breakage will show up very rapidly. (Illustrating from exhibit of photograph--refer to Figs. 2 and 4).

Mr. Silverman: That is direct transmission.

Mr. Frink: That is direct transmission, through to this one edge, the figure representing the thickness of the sample. The outside always shows the greater amount of yellow, the inside cools of course, somewhat slower, and shows less.

Mr. Silverman: The use of selenite plates for glass examination I have never before seen, and it brings out a very interesting point. Do you always examine your specimen on edge?

Mr. Frink: I always examine a specimen on edge. I usually take the transverse section, it being most acute. If it is in a hand process it does not give you any better results.

Mr. Silverman: You find a variation as you move the glass and reach different points?

Mr. Frink: Yes, in color and position of color zone.

Professor Silverman: You have shown us a number of pictures of views as they appear to you through the polarizer. I should like to know whether the color zones remain the same if you change the position of that specimen, that is, if you examine different parts of the surface by the transmitted light?

Mr. Frink: Yes, if homogeneity or strain is the same, but to examine an entire roller would take too long. How-

ever, any locality in the specimen will show the same phenomena irrespective of how it is viewed.

Mr. Binns: Do you cut a section with a wheel and the edges polished, or is it a broken specimen?

Mr. Frink: Cut it with a diamond, not polished.

Mr. Binns: Not with a wheel?

Mr. Frink: No, because a wheel will feather the edge and produce angles, and the light is not truly transmitted.

Here is a condition that is found on one side of a cylinder of glass, and here is a condition that is found on the other side, showing that here the strains are widely spread throughout while here they are concentrated all on the center. If you have noticed, the neutral point in the field is very large here and the tension part is very small as compared with this. (Referring to Figures 4 and 5.)

Mr. Silverman: Do I understand that these are the inner and outer edges of the same specimen or of two specimens taken from different parts of the cylinder?

Mr. Frink: As illustrated in cases like Fig. 1 and 2 these are specimens from the same cylinder, No. 2 being longitudinal and No. 1 transverse. This heavy yellow forms the outer edge of the cylinder of the specimen, the opposite side is the inner edge.

Mr. Silverman: I do not believe the point has yet been cleared. You know the field of your microscope is necessarily very small as far as the surface of that glass is concerned. What I want to know is, if you change the position of your glass specimen under the microscope so that at first one edge is in the field and you gradually travel toward the other edge whether you observe a difference in the picture.

Mr. Frink: I place it so as to get the center of the scope between the two edges.

Mr. Silverman: Yes, but you are showing the picture as you see it or the picture as you calculate it?

Mr. Frink: They are exact reproductions as seen by

means of a B. & L. retrographical instrument using 1 inch occular, 1½ inch objective, with solar light.

Mr. Silverman: In other words, it shows what you observed at one point in the glass.

Mr. Frink: Yes, and that point covers the whole thickness of the glass. It magnifies only about 20 times. The glass is about an eighth of an inch thick or perhaps a tenth, so the figure is about two inches wide.

Mr. Silverman: The question still arises, suppose you are to focus on a point near to the outer edge of the specimen, and then focus at another point at the middle of a specimen, and then on another point at the inside of the specimen, do you observe different results?

Mr. Frink: No, the phenomena are the same throughout, if the glass is the same in composition or in physical condition.

A PLEA FOR CO-OPERATION.*

BY

ERNEST MAYER, Beaver Falls, Pa.

As a member of both the American Ceramic Society and the United States Potters' Association, I desire to suggest that there is a mutual advantage almost amounting to a necessity for bringing these two organizations into somewhat closer touch. The only attempt in this direction, so far as I know, was made about two years ago, when the practical potters and foremen of the various manufactories in East Liverpool and vicinity formed a local society to discuss the various manufacturing problems that came up in their actual working experience. For a while the members took a great interest in the new work, and the meetings were fairly well attended. I had the privilege of attending some of these meetings, and was very much struck with the earnestness and enthusiasm shown.

This local society, if I am correctly informed, no longer exists, and if the reason given for its demise is the true one, it shows a very deplorable condition of things. In the interest of the pottery manufacturers of this section, it is important that this local club should at once be started up again, because by the interchange of ideas only can any potter reasonably hope to make any substantial progress in his business.

We all have our problems to solve, and there are only three ways of working them out:

1st. To work them out, unaided in any way.

* The above paper was prepared for presentation at the "Potters' Session" Monday afternoon, February 7th, 1910, to which a special effort had been made to bring in members of the United States Potters' Association from East Liverpool, Wheeling and surrounding territory. As will be observed, the paper is exhortatory in form and was primarily intended to bring about a discussion in which members of both bodies could take part. Mr. Mayer was prevented from presenting it in person, and for that reason it was read by title.

2nd. To turn to the literature of the subject, and seek to find whether anything has been printed by others bearing on the problem we have in hand.

3rd. By exchange of views with others who have experience along the same lines.

For each to work them out unaided is entirely too long and tedious a process and an awful waste of human energy. When one turns to the literature of the subject it usually happens that the person seeking the information finds it given in chemical terms with which he is not acquainted. This statement is intended to apply not to the ceramic chemists, but to the average pottery superintendents and foremen as we find them in our factories today. There remains as the only alternative the seeking of advice and assistance from some friend, with whom he can talk the matter over. As I view the matter, this latter is the method by which the bulk of the progress of the day has come, and on this method we must still rely.

The American potter has before him today some great problems. We all know that within our own country there are immense deposits of white burning clays, but how many American manufacturers are using American clays today? It will at once be asked what is there offered for the American manufacturer to buy? Unfortunately the answer must be that there is very little, but the principal reason why there is so little is that the American potter is very timid in making any changes in his body mixes, and does not even experiment willingly. This timidity comes in a very large measure from lack of positive information as to how far changes can be made without endangering the product.

There is much literature bearing on the subject of pottery bodies, and these limits of practical body compositions have been fairly well worked over. There is the splendid pioneer work of Dr. Seger, and a very great deal in the Transactions of both the American and the English Ceramic Societies, and in a number of books, but

unfortunately the bulk of this literature is entirely sealed to the understanding of the average foreman or burner or superintendent, because it assumes a knowledge of chemistry, and ability to use chemical formulæ, and possibly some mathematics, which they do not possess.

I am now satisfied (though I used to be of a different opinion) that if the American Ceramic Society is going to be of any practical use to the superintendents of our factories today, it must put its literature in non-technical form, so that it can be understood by those who are not able to read chemistry intelligently. We must recognize the fact, that when a man gets to middle life, it is pretty hard work for him to go to school again or to learn chemistry. The minds of most of us become inelastic and slow to take up new conceptions as we reach middle life. If a man really is eager to learn, you will at once say he will apply himself to learn to handle the chemical formulæ. Experience shows that he does not do so, and educational philosophy tells us that he does not, generally because he cannot.

The men to whom I refer are now actually in charge of the potteries, and it is to them, for the present at least, to whom we must look for changes in the status quo.

This brings me into another subject in which I am very deeply interested, viz: Why do so very few of our State University boys get into the potteries? In the first place, he gets very little show to do so. The average pottery superintendent views the man of science with suspicion, and as the practical man is now in charge, the college graduate gets very little help from him in getting a start in the industry.

As a matter of fact, most of the boys have turned their attention to the structural material industries, and are making good. We have data today in the Transactions of the American Ceramic Society from some of these university boys in the brick business that shows they are applying their engineering and chemical training to their work

in a most useful manner. Similar data coming from the potteries are very scarce indeed.

Beside the reluctance of pottery superintendents to introduce possible future rivals into the industry, the labor situation of the potteries makes it very difficult for a young student to gain a practical knowledge of potting. He can not enter the pottery except as any other man enters, and he must spend long apprenticeship in doing things that he can master in a short time, before he can get any chance at the work which really requires skill and tecnique. If he comes in as the protege of the firm, and armed with authority from the office, he can do what he likes to gain knowledge rapidly, but if he comes in as a workman, he must take his time. This situation does not prevail equally in other clay industries. College boys can get work in clay plants for their vacation periods of two or three months, and work in a dozen different capacities in a short time, gaining a wide experience. Not so in the pottery.

Another feature in this situation which most potters are unwilling to admit, or do not recognize, is the fact that the structural material clay industries are making much more rapid advances towards getting onto a sound scientific and engineering basis than the potteries, and hence they offer the best berths for young college graduates. They not only pay better wages, but they offer greater opportunity for the use of chemical and engineering training. Pottery manufacture could use the same kind of ability, but in very few cases have potters cast aside their old conservatisms and frankly gone at it, with a mind free from bias, to find where their methods can be changed.

The present tariff on pottery is not likely to remain for many years as high as it now is. The two great problems that must be solved to meet the new condition are, first, cheaper materials and second, better machinery. Both are of equal importance. The American Ceramic Society

is the source from which help will come on the material problem, at least.

At the annual meeting in Washington, December, 1907, a committee consisting of H. N. Harker, M. Collear, W. E. Vodrey and E. Mayer was appointed to investigate and report on American whiteware materials. The work that this committee was asked to do was "a thorough examination and testing of all American materials with a view of determining their comparative value for potter's use." The following is the report of that committee:

East Liverpool, Ohio, Nov. 19th, 1908.

To the United States Potter's Association, Gentlemen:—

At the annual meeting held in Washington, D. C., December, 1907, a committee was appointed to investigate and report on American materials.

The men appointed on above committee were Mr. Joshua Poole, chairman, Mr. H. N. Harker, Mr. M. Collear, Mr. W. E. Vodrey and Mr. E. Mayer.

This committee met in East Liverpool, Ohio, in May, 1908, at the request of the chairman, who stated, that for personal reasons which he explained, he could not act as a member of the committee.

At a subsequent meeting in East Liverpool, Ohio, the committee met for the purpose of formulating some plan to meet the wishes of the Convention.

The only instructions that this committee has received, were gathered from the remarks of the President at the time the committee was appointed. From his remarks, it would appear that a part of the duties of this committee "was a thorough examination and testing of all American materials, with a view of determining their comparative value for potter's use."

From the above statement, it will be seen that the task set is one that is practically impossible for the committee to accomplish, for the following reasons:

First. That in "the thorough examination and testing of all American materials," it means that a number of analytical and physical tests would have to be made, which would necessitate the employment of one or more Ceramic chemists at considerable expense, for which no provision has been made.

Second. One serious objection that has confronted this committee, is the fact that it matters not how faithfully and carefully they may follow out the wishes of the Association, that their

reports could not be made without your committee becoming the advertising medium of certain brands of American materials, which they do not care to do.

Third. This committee is of the opinion that the work, as laid out by the Association, is now being done in a more thorough and comprehensive manner by the American Ceramic Society, than could possibly be done by any committee adopted by this Association. The Transactions of the American Ceramic Society are filled with valuable, practical suggestions along every line of the pottery industry, and the fact that this committee seemed a necessity to you, was due solely to the fact that this Association has not been fully aware of the great work already done, and being done, along the line mapped out for this committee.

We respectfully recommend that the individual members of this Association do everything in their power to increase the membership and encourage the work of the American Ceramic Society, for we believe that the future success, at least from the technical side of our industry, depends in a very large measure in taking advantage of the opportunity offered by the American Ceramic Society.

Respectfully submitted,

ERNEST MAYER,
W. E. VODREY,
H. N. HARKER,
M. COLLEAR,
Committee.

This investigation of materials is a very important matter for the United States Potters' Association, but to ask a number of manufacturing potters, who have their own business to attend, to examine and test all American materials, is simply absurd. That the materials need to be tested nobody will question, but the association could only hope to get real work done by properly trained ceramic chemists and paying them for their work. If they will spend one-half the sum they now spend on matters pertaining to the tariff, they would be amply repaid at the end of the year. One of the practical results which I hope may result from this paper will be a joint committee from the United States Potters' Association and the American Ceramic Society to see whether a closer union cannot be made between the two societies.

A fact not generally known is that outside of Dr. Mellor, practically all of the men contributing the really valuable articles to the English Ceramic Society are practical manufacturing potters. This is a somewhat significant fact, for it shows that they at least are not averse to publishing valuable information to the world, and that as potters they recognize what the English Ceramic Society stands for.

I would not have made this last statement about the English Ceramic Society except for the fact that many of the American pottery manufacturers regard the American Ceramic Society as a lot of theorists, whose work has not practical use or value. In this opinion they are perfectly justified if we have done nothing to show our reliability from the practical side. Our volumes speak for themselves to those who will read them. Those who will not or cannot read them are not entitled to condemn them.

In conclusion I want to quote a few remarks made by Mr. G. P. Holdcroft, a very practical English potter, in his address as president of the English Ceramic Society:

> True protection for our trade against foreign competition is to be sought in better trained leaders of the industry; men of wider views, such as we should expect to be turned out from a central college or higher technical school. While it is dangerous to follow the lead of the inexperienced expert, it is equally dangerous to trust to the non scientific man whose only boast is experience in the narrowest rut.
>
> I agree most heartily with the chairman of the Chamber of Commerce, Mr. Giddard, who some time ago pointed out how much better our position now would be if the thousands wasted on arbitration had been devoted to the establishment of a college. It is an absolute necessity that we should have a central technical college where more advanced studies and research work can be conducted.

When I read the above I was satisfied that those sentiments expressed exactly the needs of the American potter as well as his English brother.

HEAT BALANCE OF A PLATE GLASS FURNACE.

BY

FREDERICK GELSTHARP, Charleroi, Pa.

The following calculations were made for a twenty-pot plate glass furnace of modern construction, fired with natural gas. The inside dimensions were twelve feet wide by forty-nine feet long and five feet high. The glass pots weighed about 2000 pounds each, and the average weight of glass poured from each pot was 1995 pounds per melt.

This furnace required 320,000 cubic feet of natural gas at normal pressure per melt. One cubic foot has a calorific power of 238 kilogram-calories. We will continue to use the kilogram calorie throughout these calculations. As a starting point, we will commence with the pots, returning to the furnace immediately after a cast.

Glass Pots. The pots have a temperature of about 500° C. on returning from a cast, and they will be finally heated up to 1400°C. To arrive at the heat units required, we take the specific heat of the clay as 0.1907 and the coefficient of increase per degree $1+0.00039t°$.

Then

$$Q\ (0°—t°) = 0.1907\ (1+0.00039t)t$$
$$Q\ (0°—500°) = 0.1907\ (1+0.00039\times500)\times500$$
$$Q = 113.944 \text{ calories}$$

or the kilogram calories contained per kilogram of glass pot at 500° C. In the same manner,

$$Q\ (0°—1400°) = 0.1907\ (1+0.00039\times1400)\times1400$$
$$Q = 412.748 \text{ calories}$$

The difference is the heat taken up per kilogram in heating the pot:

$$412.748—113.944 = 298.804 \text{ calories.}$$

The weight of 20 glass pots we take as 20,000 kilograms. Therefore the total heat units required to heat the pots from 500° C. to 1400° C. is

20000×298 or 5,976,000 kilogram calories.

Furnace. The furnace temperature before or at the beginning of a new melt is about 800° C., and will also be finally 1400° C. But these temperatures are superficial on the inside surface, and to estimate the units required, an average temperature for a depth of 6 inches must be taken, and this will be near 650° C. before a new melt is under way and 1000° C. at full heat.

The volume of the brick work is

$50 \times 12 \times \frac{1}{2} \times 2 = 600$ cubic feet in top and bottom
$50 \times 5 \times \frac{1}{2} \times 2 = 250$ cubic feet in two side walls
$12 \times 5 \times \frac{1}{2} \times 2 = 60$ cubic feet in two end walls

Total 910 cubic feet

$$\frac{910 \text{ cubic feet} \times 156 \text{ pounds per cubic feet}}{2.2} = 64527 \text{ kilograms}$$

$Q\,(0° - 650°) = 0.1907\,(1 + 0.00039 \times 650) \times 650 = 155.377.$
$Q\,(0° - 1000°) = 0.1907\,(1 + 0.00039 \times 1000) \times 1000 = 265.073.$
$Q\,(650° - 1000°) = 109.696$ kilogram calories per kilogram.

Therefore, the total heat units required for the furnace will be

64527 kilos $\times$ 109.696 calories = 7,078,611 kilogram calories.

Decomposition of Materials. The batch employed for melting into glass is

Silica	100 = SiO_2	100.000				
Soda Ash	32 = Na_2O	18.720	+	CO_2	13.280	
Salt Cake	6 = Na_2O	2.613	+	SO_3	3.387	
Limestone	35 = CaO	19.600	+	CO_2	15.400	
	173	140.933 (glass)			32.067 (gases)	

The heat required for the decomposition of these materials is the same as that given out on the combination of the elements in them.

For sodium carbonate we have:

$$Na_2CO_3 = Na_2O + CO_2$$
$$-273{,}700 = +100{,}900 + 97{,}200$$

e. q. Heat Units required = —75,600 gram calories per molecular weight.

$$\frac{-75600}{106} = -713.2 \text{ kilogram calories per kilogram.}$$

For salt cake:

$$Na_2SO_4 = Na_2O + SO_3$$
$$-328{,}100 = +100{,}900 + 91{,}900$$

Heat units required = —135,300 gram calories per molecular weight.

$$\frac{-135300}{142} = -952.8 \text{ kilogram calories per kilogram.}$$

For limestone:

$$CaCO_3 = CaO + CO_2$$
$$-273{,}850 = +131{,}500 + 97{,}200$$

Heat units required = — 45,150 gram calories per molecular weight.

$$\frac{-45150}{100} = -451.5 \text{ kilogram calories per kilogram.}$$

Referring back to the batch composition, we will estimate the total weight of each material used. The twenty pots will produce 18136 kilograms of glass. Hence,

$$\text{Silica required} = 18{,}136 \times \frac{100}{140.933} = 12{,}868 \text{ kilos.}$$

$$\text{Soda Ash required} = 18{,}136 \times \frac{32}{140.933} = 4{,}118 \text{ kilos.}$$

$$\text{Salt Cake required} = 18{,}136 \times \frac{6}{140.933} = 772 \text{ kilos.}$$

$$\text{Limestone required} = 18{,}136 \times \frac{35}{140.933} = 4{,}504 \text{ kilos.}$$

From these figures we can arrive at the total heat units required for decomposition, viz.:

Soda Ash	$4{,}118 \times 713.2$	$= 2{,}936{,}957$
Salt Cake	772×952.8	$= 735{,}561$
Limestone	$4{,}504 \times 451.5$	$= 2{,}033{,}556$
	Total,	5,706,074 kilogram calories

From this must be deducted the heat of formation of the respective silicates produced in melting the glass:

$$Na_2O + 2\,SiO_2 = Na_2O,\ 2\,SiO_2$$
$$-(100{,}900 + 360{,}000) = 506{,}100$$

or + 45200 gram calories per molecular weight.

Hence,

$$\frac{45200}{62} = +729 \text{ kilogram calories per kilogram of } Na_2O$$

$$\frac{45200}{106} = +426.4 \text{ kilogram calories per kilogram of } Na_2CO_3$$

In the same way, we have

$$CaO + 2\,SiO_2 = CaO,\ 2\,SiO_2$$
$$-(131{,}500 + 360{,}000) = +509{,}350$$

or + 17,850 gram calories per molecular weight

$$\frac{17850}{56} = +318 \text{ kilogram calories per kilogram of } CaO,$$

or $\frac{17850}{100} = +178.5$ kilogram calories per kilogram of $CaCO_3$.

The total heat generated by the formation of silicates therefore is:

From	$Na_2CO_3 = 4118$ kg.	× 426.4 kg. cal. =	1,755,915
From	$Na_2SO_4 = 772$ kg.	× 318.3 kg. cal. =	245,727
From	$CaCO_3 = 4504$ kg.	× 178.5 kg. cal. =	803,964
		Total = +	2,805,606

Deducting this heat of formation from the heat used in decomposition, we have

$$-5{,}706{,}074 + 2{,}808{,}606 = -2{,}900{,}468 \text{ kg. calories.}$$

as the total heat units absorbed in the combination of the ingredients of the glass.

Melting the Glass. The specific heat of glass is obtained as follows:

	Sp. Ht.		Wt.		
Na_2O	0.2250	×	21.333	=	4.80
CaO	0.1719	×	19.600	=	3.37
SiO_2	0.1833	×	100.000	=	18.33
			140.933	=	26.50

$$\frac{26.50}{140.933} = 0.188 \text{ kilogram calories per degree.}$$

$Q\ (0°—1400°) = 0.188\ (1 + 0.00039 \times 1400) \times 1400 = 406.907$ kilogram calories per kilo. of glass.

18,136 kilos glass $\times$ 406.907 = 7,3379,665 kg. calories.

To this must be added the latent heat of fusion which approximates 25% of the specific heat, or

$7{,}379{,}665 \times 5/4 = 9{,}224{,}581$ kilogram calories.

Heat Carried Away in Waste Gases. The gases from the decomposition of the materials are as follows:

For 140.933 kilos glass = 28.68 kilos CO_2
= 3.387 kilos SO_3
18,136 kilos glass = 1690 kilos CO_2
435.26 kilos SO_3
(348.21 kilos SO_2+87.05 kilos O)

The temperature at which the waste gases leave the furnace at the chimney may be taken at 375°C.

1690 kilos CO_2 at 375° C. contains:

$Q\ (0°—375°) = 1690\ (0.19 + 0.00011 \times 375) \times 375 = 146.554$ kilogram calories.

348.21 kilos SO_2 at 375° contains:

$Q\ (0°—375°) = 348.21\ (0.125 + 0.0001 \times 375) \times 375 = 21.219$ kilogram calories.

87.05 kilos O_2 at 375° C. contains:

$Q\ (0°—375°) = 87.05\ (0.2104 + 0.0000187 \times 375) \times 375 = 7.096$ kilogram calories.

Total heat carried away by gases from decomposition of raw materials = 174.869 kilogram calories.

Waste Gases from Combustion. One cubic foot of natural gas after combustion gives:

Water vapor	1.915 cubic feet
Carbonic acid	0.980 cubic feet
Nitrogen	7.43 cubic feet
Total	10.325 cubic feet

As I have at hand the data per cubic meter, it is convenient to make this calculation in that unit.

1.915 cubic meters water vapor at 375°C contains:

$Q\ (0°—375°) = 1.915\ \ (0.34 + 0.00015 \times 375) \times 375 = 284.4$ kilogram calories.

0.98 cubic meters of carbonic acid (CO_2) at 375°C contains:

$Q\ (0°—375°) = 0.98\ \ (0.37 + 0.00022 \times 375) \times 375 = 166.2$ kilogram calories.

7.43 cubic meters of nitrogen at 375°C contains:

$Q\ (0°—375°) = 7.43\ \ (0.303 + 0.000027 \times 375) \times 375 = 940.6$ kilogram calories.

Hence the total heat units in waste gases from 1 cubic meter of natural gas is

$$284.4 + 166.2 + 940.6 = 1391.2 \text{ kilogram calories.}$$

Since 320,000 cubic feet, or 9067 cubic meters, of natural gas are consumed per melt, the total units are:

$$1391.2 \times 9067 = 12{,}610{,}000 \text{ kilogram calories.}$$

To this must be added the units in the gases from decomposition products of the batch,

$$12{,}610{,}000 + 174{,}869 = 12{,}784{,}869 \text{ kilogram calories.}$$

which is the total heat going up the chimney.

Regenerators. At the finish of a melt, the regenerators have increased in temperature from about 450°C to 850°C. The weight of the brick checker-work may be taken as 50 tons or 50,000 kilograms.

$Q\ (0°—450°) = 0.1907\ \ (1 + 0.00039 \times 450) \times 450 = 100.9$ kilogram calories per kilogram.

$Q\ (0°—850°) = 0.1907\ \ (1 + 0.00039 \times 850) \times 850 = 215.8$ kilogram calories per kilogram.

$Q\ (450°—850°) = 215.8—100.9 = 114.9$ kilogram calories per kilogram.

Total heat units represented by increase of temperature of regenerators =

$$114.9 \times 50{,}000 = 5{,}745{,}000 \text{ kilogram calories.}$$

Heat Evolved.

The total heat evolved is that due to the combustion of 320,000 cubic feet of natural gas, yielding 238 kilogram calories per cubic foot, or 71,400,000 kilogram calories in total.

Radiation and Conduction.

To make this work complete, it is also necessary to calculate the heat lost by radiation and conduction, but unfortunately we have to assume so much that little or no value can be attached to such calculations. I therefore hesitate to repeat them, but think it might be interesting to note that for those quantities I arrived at a figure closely resembling that found by difference in the usual way.

SUMMARY.

The foregoing calculations give us:

	Kilogram Calories	Per Cent of the Total
Furnace	7,078,611	9.91
Regenerators	5,745,000	8.04
Glass Pots	5,976,000	8.37
Decomposition of batch	2,900,468	4.06
Contained in the glass	9,224,581	12.91
Escaping by chimney	12,784,869	17.90
Radiation and Conduction	27,690,471	38.78
Total	71,400,000	100.00

A STUDY OF THE VITRIFICATION RANGE AND DI-ELECTRIC BEHAVIOR OF SOME PORCELAINS.

BY

A. V. Bleininger, Pittsburg, Pa., and R. T. Stull, Urbana, Ill.

The object of this work, which was begun in the summer of 1908, was to show by graphical means the proportions of clay, feldspar and flint which produce vitrified clay bodies at temperatures within the limits of American practice. At the same time this opportunity was taken to show, if possible, the relation between the composition of the bodies and their electrical resistance. In order to bring out the effect of introducing the various clays used in the industries it was decided to cover the field outlined by using Tennessee ball clay No. 3, North Carolina kaolin, English China clay and Georgia kaolin. All of these materials, as well as the feldspar and flint were obtained from the works of the Mayer Pottery Company, Beaver Falls, Pa., through the kindness of Mr. Ernest Mayer and Mr. Herford Hope.

The materials were analyzed in the chemical department of the University of Illinois. The results of the analyses, as well as the empirical formulæ of these components are given in the following table:

Chemical Analysis of Materials.

	Tenn. Ball.	N. C. Kaolin	Eng. China Clay	Georgia Kaolin.	Potash Spar.
SiO_2	48.54%	45.74%	47.06%	46.86%	70.03%
Al_2O_3	36.25%	40.18%	38.70%	38.67%	17.80%
Fe_2O_3	.67%	.57%	.40%	.57%	.21%
CaO	.32%	.30%	.58%	.55%	.98%
MgO	.32%	.34%	.49%	.25%	.16%
K_2O	.70%	1.19%	1.05%	.27%	8.71%
Na_2O	.28%	.55%	.23%	.49%	1.61%
H_2O	12.13%	14.30%	12.22%	13.27%	.35%

Chemical Formulae.

Tennessee Ball Clay	.0209 K_2O .0127 Na_2O .0161 CaO .0225 MgO	1.0000 Al_2O_3 .0118 Fe_2O_3	2.276 SiO_2
	.0722	Mol. Wt. = 279.173	
North Carolina Kaolin	.0321 K_2O .0225 Na_2O .0136 CaO .0216 MgO	1.0000 Al_2O_3 .0090 Fe_2O_3	1.935 SiO_2
	.0898	Mol. Wt. = 261.898	
English China Clay	.0294 K_2O .0098 Na_2O .0273 CaO .0323 MgO	1.0000 Al_2O_3 .0066 Fe_2O_3	2.067 SiO_2
	.0988	Mol. Wt. = 265.507	
Georgia Kaolin..	.0076 K_2O .0208 Na_2O .0258 CaO .0164 MgO	1.0000 Al_2O_3 .0094 Fe_2O_3	2.055 SiO_2
	.0706	Mol. Wt. = 275.816	
Potash Spar	.5283 K_2O .1480 Na_2O .0998 CaO .0228 MgO	1.0000 Al_2O_3 .0075 Fe_2O_3	6.655 SiO_2
	.7989	Mol. Wt. = 569.832	

The scheme of compounding the bodies was simple. Starting with a mixture of 50% of clay and 50% of feldspar the latter was gradually replaced by flint down to a content of 5% feldspar. The amount of clay was then increased to 55% and again the feldspar replaced as before. This was continued until a clay content of 80% was reached.

In table I the composition of the bodies and their formulæ are given.

Preparation of Specimens.

The clays were blunged and screened in the usual manner, and from the prepared bodies two kinds of specimens were made. For the purpose of obtaining measurements of the porosity at different temperatures small

TABLE I.

	No.	BATCH			FORMULA						
		Ga. Kaol.	Spar.	Flint	K_2O	Na_2O	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2
A	1	100	0	0	.0076	.0208	.0258	.0164	1.000	.0095	2.055
	2	50	50	0	.1777	.0625	.0502	.0186	1.000	.0089	3.555
	3	50	45	5	.1660	.0596	.0485	.0185	1.000	.0088	3.675
	4	50	40	10	.1531	.0565	.0443	.0184	1.000	.0091	4.002
	5	50	35	15	.1397	.0535	.0449	.0181	1.000	.0091	4.249
	6	50	30	20	.1248	.0496	.0427	.0180	1.000	.0090	4.513
	7	50	25	25	.1093	.0458	.0404	.0180	1.000	.0094	4.850
	8	50	20	30	.0925	.0416	.0379	.0176	1.000	.0093	5.113
	9	50	15	35	.0742	.0323	.0352	.0174	1.000	.0092	5.450
	10	50	10	40	.0534	.0322	.0322	.0171	1.000	.0091	5.817
	11	50	5	45	.0316	.0268	.0295	.0168	1.000	.0095	4.216
	12	55	45	0	.1555	.0571	.0476	.0183	1.000	.0090	3.359
	13	55	40	5	.1430	.0541	.0452	.0182	1.000	.0093	3.557
	14	55	35	10	.1303	.0598	.0437	.0180	1.000	.0092	3.775
	15	55	30	15	.1163	.0476	.0416	.0178	1.000	.0091	4.008
	16	55	25	20	.1015	.0440	.0395	.0177	1.000	.0095	4.254
	17	55	20	25	.0857	.0401	.0371	.0175	1.000	.0094	4.520
	18	55	15	30	.0682	.0359	.0346	.0173	1.000	.0093	4.807
	19	55	10	35	.0498	.0314	.0318	.0170	1.000	.0092	5.114
	20	55	5	40	.0293	.0264	.0293	.0168	1.000	.0096	5.456
	21	60	40	0	.1349	.0502	.0438	.0181	1.000	.0090	3.178
	22	60	35	5	.1226	.0440	.0423	.0179	1.000	.0089	3.367
	23	60	30	10	.1088	.0457	.0402	.0177	1.000	.0089	3.556
	24	60	25	15	.0953	.0425	.0383	.0177	1.000	.0091	3.781
	25	60	20	20	.0804	.0388	.0360	.0174	1.000	.0091	4.015
	26	60	15	25	.0640	.0349	.0337	.0172	1.000	.0090	4.262
	27	60	10	30	.0468	.0307	.0311	.0170	1.000	.0089	4.527
	28	60	5	35	.0279	.0261	.0287	.0168	1.000	.0093	4.813
	29	65	35	0	.1154	.0471	.0414	.0178	1.000	.0091	3.006
	30	65	30	5	.1027	.0441	.0396	.0174	1.000	.0090	3.187
	31	65	25	10	.0893	.0408	.0375	.0175	1.000	.0093	3.368
	32	65	20	15	.0754	.0373	.0355	.0173	1.000	.0092	3.571
	33	65	15	20	.0599	.0336	.0332	.0172	1.000	.0092	3.790
	34	65	10	25	.0438	.0296	.0308	.0170	1.000	.0091	4.021
	35	65	5	30	.0262	.0254	.0286	.0168	1.000	.0094	4.266
	36	70	30	0	.0973	.0427	.0392	.0176	1.000	.0091	2.846
	37	70	25	5	.0847	.0397	.0370	.0175	1.000	.0094	3.013
	38	70	20	10	.0717	.0364	.0350	.0173	1.000	.0093	3.192
	39	70	15	15	.0568	.0329	.0329	.0172	1.000	.0094	3.381
	40	70	10	20	.0417	.0291	.0306	.0170	1.000	.0092	3.582
	41	70	5	25	.0252	.0252	.0286	.0168	1.000	.0095	3.796
	42	75	25	0	.0801	.0380	.0361	.0174	1.000	.0092	2.692
	43	75	21	4	.0700	.0363	.0347	.0170	1.000	.0092	2.788
	44	75	17	8	.0593	.0335	.0335	.0172	1.000	.0090	2.625
	45	75	13	12	.0472	.0303	.0310	.0166	1.000	.0090	3.028
	46	75	9	16	.0362	.0278	.0299	.0170	1.000	.0090	3.236
	47	75	5	20	.0239	.0285	.0282	.0168	1.000	.0093	3.387

TABLE I—Continued

	No.	BATCH			FORUMLA						
		Ga. Kaol.	Spar	Flint	K_2O	Na_2O	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2
A	48	75	1	24	.0109	.0218	.0282	.0163	1.000	.0092	3.549
	49	80	20	0	.0640	.0346	.0339	.0173	1.000	.0092	2.552
	50	80	17	3	.0563	.0328	.0328	.0172	1.000	.0090	2.639
	51	80	14	6	.0483	.0308	.0318	.0172	1.000	.0092	2.733
	52	80	11	9	.0401	.0291	.0304	.0168	1.000	.0091	2.829
	53	80	8	12	.0314	.0270	.0293	.0168	1.000	.0092	2.927
	54	80	5	15	.0228	.0250	.0281	.0167	1.000	.0094	3.278
	55	80	2	18	.0140	.0225	.0268	.0167	1.000	.0092	3.134
		Tenn. Ball.									
B	1	100	0	0	.0209	.0127	.0161	.0225	1.000	.0118	2.276
	2	50	50	0	.1876	.0573	.0438	.0225	1.000	.0105	3.715
	3	50	45	5	.1764	.0543	.0415	.0225	1.000	.0105	3.937
	4	50	40	10	.1636	.0509	.0393	.0224	1.000	.0108	4.177
	5	50	35	15	.1502	.0472	.0378	.0224	1.000	.0108	4.432
	6	50	30	20	.1359	.0436	.0354	.0224	1.000	.0108	4.707
	7	50	25	25	.1206	.0395	.0327	.0224	1.000	.0112	5.000
	8	50	20	30	.1041	.0350	.0300	.0224	1.000	.0112	5.327
	9	50	15	35	.0857	.0302	.0268	.0224	1.000	.0112	5.677
	10	50	10	40	.0661	.0250	.0234	.0224	1.000	.0112	6.058
	11	50	5	45	.0442	.0192	.0202	.0223	1.000	.0117	6.471
	12	55	45	0	.1663	.0515	.0402	.0224	1.000	.0105	3.528
	13	55	40	5	.1542	.0483	.0382	.0224	1.000	.0109	3.738
	14	55	35	10	.1416	.0449	.0364	.0225	1.000	.0108	3.951
	15	55	30	15	.1276	.0401	.0340	.0224	1.000	.0108	4.195
	16	55	25	20	.1133	.0374	.0311	.0224	1.000	.0112	4.455
	17	55	20	25	.0980	.0332	.0289	.0224	1.000	.0112	4.735
	18	55	15	30	.0806	.0287	.0260	.0224	1.000	.0112	5.027
	19	55	10	35	.0599	.0227	.0218	.0214	1.000	.0107	5.111
	20	55	5	40	.0424	.0185	.0200	.0223	1.000	.0116	5.700
	21	60	40	0	.1459	.0463	.0368	.0224	1.000	.0109	3.354
	22	60	35	5	.1339	.0435	.0351	.0224	1.000	.0109	3.550
	23	60	30	10	.1207	.0400	.0329	.0224	1.000	.0108	3.760
	24	60	25	15	.1070	.0359	.0305	.0225	1.000	.0112	3.984
	25	60	20	20	.0924	.0320	.0280	.0224	1.000	.0112	4.224
	26	60	15	25	.0763	.0279	.0253	.0224	1.000	.0112	4.482
	27	60	10	30	.0509	.0232	.0223	.0223	1.000	.0112	4.758
	28	60	5	35	.0407	.0183	.0197	.0223	1.000	.0116	5.059
	29	65	35	0	.1271	.0411	.0340	.0224	1.000	.0109	3.189
	30	65	30	5	.1145	.0378	.0319	.0224	1.000	.0109	3.725
	31	65	25	10	.1016	.0343	.0297	.0224	1.000	.0112	3.494
	32	65	20	15	.0877	.0306	.0272	.0224	1.000	.0112	3.781
	33	65	15	20	.0726	.0266	.0247	.0224	1.000	.0112	4.001
	34	65	10	25	.0568	.0224	.0220	.0224	1.000	.0112	4.245
	35	65	5	30	.0393	.0178	.0194	.0224	1.000	.0116	4.504
	36	70	30	0	.1088	.0363	.0310	.0224	1.000	.0110	3.035
	37	70	25	5	.0964	.0329	.0282	.0224	1.000	.0111	3.244
	38	70	20	10	.0833	.0294	.0266	.0224	1.000	.0112	3.398
	39	70	15	15	.0689	.0257	.0245	.0224	1.000	.0112	3.595
	40	70	10	20	.0541	.0216	.0216	.0224	1.000	.0112	3.805

TABLE I--Continued.

	No.	BATCH			FORUMLA						
		Tenn. Ball.	Spa	Flint	K_2O	Na_2O	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2
B	41	70	5	25	.0339	.0173	.0193	.0224	1.000	.0115	4.030
	42	75	25	0	.0922	.0317	.0282	.0224	1.000	.0112	2.891
	43	75	21	4	.0822	.0291	.0265	.0223	1.000	.0111	3.022
	44	75	17	8	.0717	.0261	.0248	.0224	1.000	.0111	3.159
	45	75	13	12	.0607	.0234	.0230	.0223	1.000	.0113	3.305
	46	75	9	16	.0488	.0202	.0212	.0223	1.000	.0112	3.457
	47	75	5	20	.0368	.0170	.0191	.0223	1.000	.0115	3.619
	48	75	1	24	.0241	.0137	.0170	.0222	1.000	.0115	3.787
	49	80	20	0	.0765	.0277	.0252	.0224	1.000	.0115	2.753
	50	80	17	3	.0689	.0256	.0240	.0224	1.000	.0114	2.846
	51	80	14	6	.0611	.0235	.0228	.0225	1.000	.0115	2.942
	52	80	11	9	.0530	.0216	.0213	.0222	1.000	.0115	3.041
	53	80	8	12	.0446	.0195	.0200	.0223	1.000	.0116	3.151
	54	80	5	15	.0359	.0169	.0186	.0223	1.000	.0118	3.251
	55	80	2	18	.0238	.0145	.0173	.0224	1.000	.0117	3.456
		N. C. Kaol.									
C	1	100	0	0	.0321	.0225	.0136	.0216	1.000	.0090	1.935
	2	50	50	0	.1884	.0621	.0409	.0219	1.000	.0086	3.420
	3	50	45	5	.1774	.0593	.0352	.0219	1.000	.0085	3.623
	4	50	40	10	.1654	.0563	.0364	.0218	1.000	.0088	3.842
	5	50	35	15	.1530	.0531	.0349	.0218	1.000	.0087	4.073
	6	50	30	20	.1392	.0496	.0324	.0218	1.000	.0087	4.323
	7	50	25	25	.1248	.0460	.0298	.0217	1.000	.0085	4.591
	8	50	20	30	.1093	.0420	.0270	.0217	1.000	.0089	4.880
	9	50	15	35	.0921	.0378	.0239	.0217	1.000	.0088	5.192
	10	50	10	40	.0739	.0331	.0206	.0216	1.000	.0087	5.532
	11	50	5	45	.0535	.0280	.0175	.0215	1.000	.0090	5.898
	12	55	45	0	.1678	.0567	.0374	.0218	1.000	.0086	3.224
	13	55	40	5	.1207	.0539	.0354	.0218	1.000	.0089	3.417
	14	55	35	10	.1444	.0508	.0335	.0217	1.000	.0088	3.616
	15	55	30	15	.1313	.0476	.0312	.0217	1.000	.0087	3.832
	16	55	25	20	.1177	.0441	.0287	.0216	1.000	.0090	4.061
	17	55	20	25	.1033	.0400	.0261	.0216	1.000	.0090	4.312
	18	55	15	30	.0872	.0364	.0233	.0216	1.000	.0089	4.577
	19	55	10	35	.0703	.0321	.0202	.0215	1.000	.0089	4.863
	20	55	5	40	.0517	.0274	.0174	.0215	1.000	.0090	5.171
	21	60	40	0	.1483	.0520	.0337	.0217	1.000	.0087	3.037
	22	60	35	5	.1372	.0493	.0321	.0217	1.000	.0086	3.225
	23	60	30	10	.1245	.0461	.0298	.0216	1.000	.0085	3.404
	24	60	25	15	.1117	.0432	.0275	.0216	1.000	.0088	3.609
	25	60	20	20	.0980	.0394	.0250	.0216	1.000	.0087	3.823
	26	60	15	25	.0830	.0356	.0223	.0215	1.000	.0086	4.053
	27	60	10	30	.0673	.0316	.0195	.0215	1.000	.0085	4.299
	28	60	5	35	.0500	.0273	.0168	.0215	1.000	.0088	4.559
	29	65	35	0	.1303	.0471	.0310	.0216	1.000	.0087	2.867
	30	65	30	5	.1153	.0446	.0289	.0216	1.000	.0086	3.036
	31	65	25	10	.1065	.0414	.0267	.0216	1.000	.0089	3.214
	32	65	20	15	.0935	.0381	.0244	.0216	1.000	.0089	3.401
	33	65	15	20	.0794	.0346	.0219	.0215	1.000	.0087	3.601

TABLE I—Continued.

	No.	BATCH			FORUMLA						
		N. C. Kaol.	Spar	Flint	K_2O	Na_2O	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2
C	34	65	10	25	.0647	.0309	.0192	.0214	1.000	.0086	3.815
	35	65	5	30	.0486	.0268	.0167	.0214	1.000	.0089	4.045
	36	70	30	0	.1145	.0431	.0247	.0218	1.000	.0088	2.680
	37	70	25	5	.1019	.0401	.0257	.0215	1.000	.0090	2.892
	38	70	20	10	.0899	.0370	.0235	.0215	1.000	.0089	3.067
	39	70	15	15	.0763	.0337	.0211	.0215	1.000	.0089	3.243
	40	70	10	20	.0624	.0302	.0186	.0214	1.000	.0088	3.428
	41	70	5	25	.0474	.0264	.0163	.0214	1.000	.0090	3.632
	42	75	25	0	.0979	.0391	.0254	.0216	1.000	.0090	2.231
	43	75	21	4	.0885	.0369	.0235	.0214	1.000	.0090	2.681
	44	75	17	8	.0788	.0342	.0219	.0215	1.000	.0090	2.802
	45	75	13	12	.0686	.0317	.0201	.0214	1.000	.0090	2.932
	46	75	9	16	.0576	.0288	.0182	.0215	1.000	.0090	2.066
	47	75	5	20	.0464	.0261	.0163	.0214	1.000	.0090	3.206
	48	75	1	24	.0347	.0233	.0142	.0212	1.000	.0090	3.353
	49	80	20	0	.0835	.0355	.0226	.0217	1.000	.0089	2.451
	50	80	17	3	.0763	.0337	.0215	.0218	1.000	.0087	2.504
	51	80	14	6	.0691	.0318	.0203	.0218	1.000	.0088	2.588
	52	80	11	9	.0616	.0302	.0188	.0216	1.000	.0086	2.678
	53	80	8	12	.0538	.0281	.0175	.0216	1.000	.0087	2.764
	54	80	5	15	.0459	.0261	.0162	.0217	1.000	.0089	2.863
	55	80	2	18	.0379	.0239	.0149	.0217	1.000	.0090	2.959
		Eng. China									
D	1	100	0	0	.0294	.0098	.0273	.0323	1.000	.0066	2.067
	2	50	50	0	.1880	.0536	.0504	.0293	1.000	.0069	3.525
	3	50	45	5	.1770	.0505	.0487	.0296	1.000	.0067	3.734
	4	50	40	10	.1648	.0472	.0468	.0298	1.000	.0069	3.957
	5	50	35	15	.1480	.0436	.0332	.0300	1.000	.0068	4.192
	6	50	30	20	.1382	.0398	.0431	.0303	1.000	.0066	4.452
	7	50	25	25	.1236	.0358	.0409	.0306	1.000	.0069	4.728
	8	50	20	30	.1079	.0313	.0385	.0309	1.000	.0067	5.003
	9	50	15	35	.0904	.0266	.0360	.0312	1.000	.0066	5.348
	10	50	10	40	.0718	.0214	.0330	.0315	1.000	.0064	5.698
	11	50	5	45	.0513	.0157	.0304	.0320	1.000	.0066	6.077
	12	55	45	0	.1675	.0480	.0475	.0297	1.000	.0070	3.334
	13	55	40	5	.1558	.0447	.0458	.0299	1.000	.0072	3.529
	14	55	35	10	.1437	.0413	.0443	.0302	1.000	.0071	3.692
	15	55	30	15	.1304	.0377	.0423	.0303	1.000	.0069	3.956
	16	55	25	20	.1168	.0338	.0402	.0306	1.000	.0072	4.197
	17	55	20	25	.1020	.0297	.0380	.0314	1.000	.0070	4.453
	18	55	15	30	.0857	.0253	.0356	.0317	1.000	.0069	4.729
	19	55	10	35	.0686	.0204	.0330	.0316	1.000	.0067	5.023
	20	55	5	40	.0495	.0153	.0306	.0320	1.000	.0071	5.340
	21	60	40	0	.1475	.0425	.0446	.0300	1.000	.0071	3.150
	22	60	35	5	.1360	.0393	.0431	.0303	1.000	.0070	3.336
	23	60	30	10	.1235	.0359	.0405	.0313	1.000	.0068	3.531
	24	60	25	15	.1104	.0322	.0382	.0308	1.000	.0070	3.738
	25	60	20	20	.0965	.0283	.0371	.0310	1.000	.0069	3.961
	26	60	15	25	.0812	.0242	.0349	.0305	1.000	.0067	4.197

TABLE I—Continued.

No.	BATCH			FORUMLA						
	Eng. China	Spar	Flint	K_2O	Na_2O	CaO	MgO	Al_2O_3	Fe_2O_2	SiO_2
D 27	60	10	30	.0653	.0197	.0324	.0316	1.000	.0065	4.451
28	60	5	35	.0477	.0149	.0302	.0319	1.000	.0068	4.719
29	65	35	0	.1296	.0375	.0421	.0304	1.000	.0069	2.987
30	65	30	5	.1176	.0343	.0403	.0306	1.000	.0067	3.159
31	65	25	10	.1053	.0308	.0384	.0308	1.000	.0069	3.342
32	65	20	15	.0921	.0271	.0364	.0311	1.000	.0068	3.534
33	65	15	20	.0778	.0232	.0343	.0309	1.000	.0066	3.746
34	65	10	25	.0629	.0190	.0320	.0316	1.000	.0065	3.963
35	65	5	30	.0465	.0146	.0300	.0319	1.000	.0067	4.198
36	70	30	0	.1122	.0326	.0395	.0307	1.000	.0067	2.831
37	70	25	5	.1005	.0296	.0377	.0309	1.000	.0068	2.993
38	70	20	10	.0881	.0261	.0358	.0311	1.000	.0069	3.169
39	70	15	15	.0745	.0224	.0338	.0314	1.000	.0065	3.345
40	70	10	20	.0605	.0185	.0316	.0316	1.000	.0064	3.554
41	70	5	25	.0451	.0143	.0297	.0319	1.000	.0066	3.745
42	75	25	0	.0971	.0285	.0371	.0309	1.000	.0071	2.684
43	75	21	4	.0868	.0260	.0338	.0310	1.000	.0068	2.800
44	75	17	8	.0771	.0231	.0342	.0313	1.000	.0067	2.932
45	75	13	12	.0668	.0203	.0321	.0314	1.000	.0069	3.062
46	75	9	16	.0557	.0176	.0315	.0320	1.000	.0069	3.205
47	75	5	20	.0443	.0144	.0295	.0319	1.000	.0069	3.350
48	75	1	24	.0323	.0109	.0279	.0320	1.000	.0067	3.503
49	80	20	0	.0814	.0244	.0348	.0315	1.000	.0068	2.546
50	80	17	3	.0743	.0223	.0338	.0320	1.000	.0066	2.631
51	80	14	6	.0669	.0203	.0328	.0319	1.000	.0068	2.718
52	80	11	9	.0594	.0181	.0316	.0319	1.000	.0069	2.812
53	80	8	12	.0514	.0162	.0304	.0320	1.000	.0066	2.906
54	80	5	15	.0432	.0142	.0294	.0322	1.000	.0068	3.005
55	80	2	18	.0351	.0114	.0282	.0321	1.000	.0066	3.150

brickettes were molded, weighing from 25 to 30 grams in the burnt condition. For obtaining the electrical resistance small dishes of the shape shown in Fig. 1 were jiggered. These dishes had a diameter of about 3 3/16 inch, and a depth of 1¼ inch in the burnt state. All of the test pieces were burnt in saggers in a coal fired down-draft kiln, and special attention was paid to the observation of the temperatures by distributing cones throughout the kiln. The length of burning varied from 36 to more than 48 hours.

After burning, the porosity of the brickettes was determined in the manner repeatedly described in the Trans-

actions of this society. In addition, the specific gravity of the pulverized brickettes was determined by means of the pycnometer. After grinding the porcelain specimens in the jaw crusher and in iron mortars, pains were taken to remove the metallic particles by means of a magnet. The true specific gravity of the bodies was determined primarily for the purpose of obtaining the volume of the enclosed pore space, for which it was hoped to establish some relation as regards temperature and content of feldspar.

The specimens for the electrical tests were selected by inspection from the burns, which resulted in apparently vitrified bodies. The puncture tests were conducted in the Electrical Laboratory of the University of Illinois, under the direction of Mr. Thomas H. Amrine. The arrangement of the specimen for the test is shown in Fig. 1. The readings of the voltmeter below 10,000 volts were not as accurate as was desired, and it would have been better if the thickness had been greater, as the instrument was designed for readings above 10,000 volts.

The results of this work expressed in graphical form, in which they tell their own story, are discussed under the following headings:

1. Composition areas showing the mixtures resulting in vitrified bodies at several temperatures. All bodies absorbing not more than 0.1% of water, by weight, upon boiling in vacuo are considered vitrified. The compositions are plotted by means of triaxial diagrams and are expressed in simple percentages of clay, feldspar and flint.

2. Composition areas plotted in a rectangular coordinate system, the abscissae representing molecular equivalents of the RO constituents and the ordinates molecules of silica.

This system is used simply as a means of classification for the purpose of outlining the general effect of chemical composition. The writers fully recognize the fact that we are here not dealing with homogeneous igneous compounds and solutions, owing to the fact that the materials are not

reduced to maximum fineness and that the viscosity is still so great that no appreciable deformation of the burnt specimens is observable at the temperatures employed. However, the fact remains that these mixtures are blended sufficiently intimate and soften enough to bring about molecular interaction which, though far from having reached equilibrium conditions, still justifies the use of chemical nomenclature. It might be suggested that the mineral composition be used as the basis of comparison, but this likewise is open to the objection that we must assume the presence of clay and feldspar corresponding to theoretical formulæ. From the standpoint of fact there should be no objection to the use of the empirical formula based as it is upon knowledge of a positive kind, the results of the chemical analysis. The boundary curves in the nature of the case are fixed by the burning conditions which prevailed in carrying out these tests. Longer burning would tend to lower the vitrification temperature, shorter burning would raise it.

3. In this group the apparent porosity at cone 9-10 is correlated with the feldspar-flint content for 50 and 60% of clay.

4. The diagrams of this group illustrate the decrease in porosity with increasing temperatures, i. e., they express the progress of vitrification. These data are presented for varying feldspar-flint contents for both 50 and 60% of clay.

5. In these diagrams the decrease in true specific gravity with increasing temperatures is shown for various proportions of feldspar and flint. The data of two series with 50 and 60% of clay are presented. In previous work the fact that the true specific gravity of silicates decreases as fusion progresses has been sufficiently brought out and is here again illustrated. It might be said in this respect that the determination of the true specific gravity was decided upon principally for the purpose of calculating the volume of the enclosed pore space, the "bleb" structure

of Purdy, but on plotting the curves it was found that these relations were exceedingly irregular. It was shown roughly that the enclosed pore space increased with the feldspar content but it also appeared that the initial structure of the body, the varying degree of density attained in molding, the amount of water employed, etc., is an important factor in this respect, which precluded the possibility of showing any simple correlation.

6. In this group the composition of the bodies is again presented by means of triaxial diagrams, and the di-electric strength shown by the jiggered vitrified test pieces

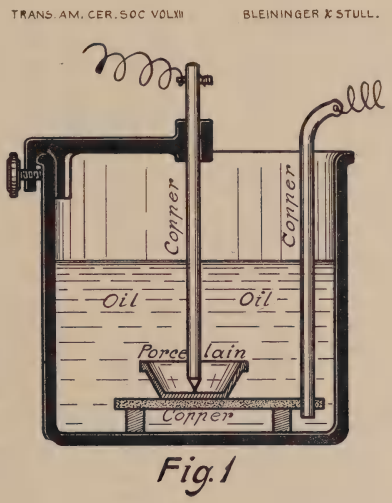


Fig. 1

is indicated by areas representing voltages per mm. of less than 10,000 volts, of 10000-14000 volts and of from 14000-18000 volts. Table II shows the voltages for the various mixtures at several burning temperatures.

TABLE II.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Volts per mm.
A 1	12+	45,820	3.15	46,188	14,546
	13	26,680	3.13	27,080	8,581
2	6½	37,480	2.52	47,225	14,873
	9	34,400	2.70	40,454	12,741
	12+	35,100	2.83	39,382	12,403
3	9	32,600	2.62	39,316	12,400
	12+	37,000	2.70	43,512	13,700
	13	27,000	2.64	32,454	10,227
4	9	38,600	2.95	41,534	13,085
	12+	53,970	2.97	57,640	18,172
	13	30,640	2.66	36,584	11,520
5	10	40,700	3.08	41,962	13,214
	13	37,800	2.48	48,422	15,322
	12+	55,040	3.13	55,866	17,585
	13	34,780	2.74	40,310	12,700
6	12+	36,240	2.79	41,314	12,989
	13	41,100	2.96	44,059	13,885
7	12+	47,960	2.94	51,749	16,313
	13	.....	....	.....	.....
8	12	33,500	3.06	34,773	10,944
	12+	33,500	3.13	34,003	10,703
	13	28,500	3.08	29,384	9,285
9	12½	35,860	3.03	37,545	11,835
	13	.....	....	.....	.....
10	13	.....	....	.....	.....
11	12½	.....	....	.....	.....
	13	38,600	3.01	40,685	12,824
12	6½	49,620	2.72	57,956	18,242
	10	45,610	2.92	49,578	15,620
	12+	31,490	3.00	33,317	10,496
13	12+	38,980	3.06	40,461	12,738
	13	43,400	3.02	45,570	14,371
14	12+	39,170	3.03	41,011	12,927
15	12+	40,120	2.94	43,290	13,646
	13	39,360	2.98	41,918	13,208
16	12+	43,580	3.07	45,236	14,195
	13	38,120	3.24	37,358	11,765
17	12	32,600	2.70	38,338	12,074
	12+	38,280	2.95	41,189	12,976
	12½	47,780	2.79	54,469	17,125
	13	27,750	2.93	30,053	9,471
18	12	23,700	3.06	24,601	7,745
	12½	23,700	3.10	24,269	7,645
	13	.....	....	.....	.....
19	12	.....	....	.....	.....
	13	.....	....	.....	.....
20	12	.....	....	.....	.....
	12½	.....	....	.....	.....

TABLE II—Continued.

No.	Cone	Total Punc Voltage	Thickness mm.	Punc. ⅛ in Volts	Punc. Volts per mm.
A 21	12+	43,660	2.82	49,161	15,482
	12½	38,980	2.80	44,142	13,914
	13	40,500	2.70	47,628	15,000
22	6	40,500	2.91	44,185	13,917
	12+	41,100	2.76	47,306	14,891
	13	32,750	2.74	37,976	11,952
23	12+	41,100	2.76	47,306	14,891
	13	37,000	2.85	41,218	12,982
24	12+	44,300	2.89	48,641	15,328
	13	40,100	2.93	43,328	13,686
25	12+	35,660	2.91	38,905	12,254
	13	44,490	2.70	52,320	16,477
[illegible]	13	.....	....	.....	.....
27	13	.....	....	.....	.....
28	13	.....	....	.....	.....
29	12+	37,800	2.66	45,133	14,210
	12½	41,700	2.60	50,916	16,038
	13	33,500	2.62	40,568	12,786
30	12+	35,100	2.92	38,154	12,020
	12½	44,680	2.77	51,248	16,130
	13	43,940	2.87	48,598	15,310
31	13	42,860	2.91	46,760	14,732
32	12½	38,280	2.94	41,304	13,020
	13	38,280	2.80	43,448	13,671
33	12½	31,320	2.88	34,515	10,867
	13	26,840	2.76	30,893	9,724
34	12½	.....	....	.....	.....
	13	.....	....	.....	.....
35	13	.....	....	.....	.....
36	11	39,360	2.84	44,004	13,859
	12½	41,700	2.83	46,787	14,731
37	6	26,040	2.57	32,160	10,132
	11	43,580	2.82	49,071	15,453
	13	33,050	2.78	37,810	11,888
38	11	26,840	2.96	28,772	9,067
	12	23,700	2.81	26,781	8,434
	13	39,360	2.97	42,036	13,253
39	12	23,700	2.54	29,625	9,330
	12½	23,700	2.87	26,212	8,257
	13	33,050	2.73	38,470	12,106
		34,140	2.81	38,578	12,146
40	12	.....	....	.....	.....
	12½	.....	....	.....	.....
	13	.....	....	.....	.....
41	12	25,060	3.73	21,351	6,718
	12½	.....	....	.....	.....
	13	.....	....	.....	.....
42	11	29,660	3.17	29,719	9,356
	12½	34,140	3.21	33,764	10,636
	13	39,740	3.07	41,131	12,945

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Volts per mm.
A 43	11	32,600	3.27	30,655	9,970
	12	45,060	3.08	46,467	14,630
	13	29,940	3.18	29,937	9,415
44	12	30,980	3.26	30,175	9,503
	12½	38,280	3.36	36,175	11,393
	13	23,700	3.23	23,297	7,338
45	6	30,300	3.30	29,149	9,182
	12	25,400	3.32	24,282	7,651
	12½	.....	....	.....	.....
	13	22,680	3.37	21,565	6,730
46	12½	25,400	3.47	23,241	7,323
47	12½	23,700	3.46	21,757	6,850
	13	.....	....	.....	.....
48	13	.....	....	.....	.....
49	13	37,960	3.10	38,871	12,245
50	13	36,240	3.31	34,754	10,948
51	13	39,740	3.06	41,250	12,987
52	13	29,220	3.15	29,453	9,276
53	13	26,200	3.24	25,676	8,086
54	13	26,040	3.36	24,607	7,750
55	13	23,700	3.42	21,993	6,930
B 1	10½	34,620	2.77	39,659	12,498
	11	33,500	3.08	34,539	10,876
	12	36,430	2.83	40,874	12,873
	12½	32,300	2.60	39,438	12,423
2	6½	48,300	3.30	46,469	14,636
	10	45,250	3.26	44,074	13,880
	10½	46,010	3.21	45,504	14,333
3	6½	42,300	3.20	41,962	13,220
	10	43,760	3.33	41,894	13,141
	10½	51,700	3.24	50,666	15,957
4	6½	48,520	3.27	45,113	14,838
	8½	48,960	3.31	46,953	14,770
	10½	50,280	3.55	44,950	14,163
5	8½	49,400	3.25	48,264	15,200
	11	48,960	3.28	47,393	14,927
	12¼	42,300	3.32	40,439	12,741
6	8½	43,400	3.30	41,751	13,152
	11	43,220	3.19	43,080	13,548
	12¼	47,460	3.40	44,328	13,960
7	8½	38,980	3.12	39,682	12,494
	11	41,900	3.02	43,995	13,874
	12¼	39,170	3.09	40,228	12,676
8	10	35,670	3.23	35,064	11,043
	12+	28,860	3.30	27,763	8,745
	12¼	48,740	3.12	49,617	15,622
9	12	36,430	3.12	37,086	11,676
	12+	48,300	3.20	47,914	15,094
10	12	33,200	3.54	29,780	9,380

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. 1/8 in. Volts	Punc. Volts per mm.
B 11	12	24,720	3.60	21,793	6,866
12	6½	40,500	3.21	40,055	12,617
	8½	40,700	3.23	40,008	12,600
	12¼	30,470	3.34	28,977	9,123
13	6½	44,300	3.21	43,713	13,800
	8½	39,930	2.95	41,965	13,535
	12+	25,720	3.46	23,611	7,404
14	6½	38,600	3.31	37,017	11,360
	9	29,580	3.17	29,639	9,331
	10	31,830	3.26	31,002	9,764
	12+	32,750	3.36	30,949	9,747
15	6½	41,700	3.33	39,740	12,523
	10	45,530	3.26	44,346	13,963
	12	38,280	3.54	34,337	10,814
16	6½	47,460	3.26	46,226	14,558
	8½	58,830	3.22	58,006	18,276
	12	54,180	3.32	51,796	16,320
17	8½	40,310	3.46	37,005	11,650
	10	33,660	3.25	32,886	10,357
	12	49,350	3.09	50,682	15,971
	12+	49,180	3.12	50,065	15,763
18	12	53,920	3.18	53,870	16,956
	12¼	53,340	3.02	56,007	17,662
19	12	36,050	3.09	37,023	11,666
	12¼	33,980	3.05	35,373	11,141
20	12	39,360	3.47	36,015	11,343
	12¼	29,760	3.24	29,155	9,186
	12½	41,300	3.35	39,152	12,330
21	6½	45,630	3.19	45,448	14,304
	9	44,490	3.17	44,579	14,035
	12+	34,140	3.26	33,252	10,472
22	6½	47,620	3.11	48,621	15,312
	9	44,870	3.02	47,114	14,858
	12+	42,860	3.08	44,189	13,915
23	8½	38,600	3.06	40,067	12,614
	12+	44,680	3.15	45,037	14,184
	12½	36,620	2.59	44,860	14,140
	13	42,100	2.98	44,839	14,127
24	8½	51,100	3.06	53,042	16,700
	12+	40,900	3.04	42,700	14,046
	13	55,040	3.22	54,269	17,100
25	8½	39,450	3.06	40,949	12,892
	12+	45,440	3.17	45,531	14,334
	12½	27,900	2.76	32,113	10,110
	13	43,940	3.04	45,873	14,454
26	8½	50,280	3.02	52,994	16,649
	12+	46,200	3.13	46,893	14,760
	13	40,100	2.95	43,148	13,614

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Volts per mm.
B 27	12	27,900	3.17	27,956	8,801
	12+	46,830	3.07	48,422	14,928
	12½	55,480	3.13	56,312	17,725
	13	45,250	3.04	47,241	14,885
28	12+	33,810	3.27	32,830	10,340
	12½	34,140	3.16	34,311	10,804
	13	33,050	3.22	32,627	10,264
29	6½	47,040	2.96	50,427	15,892
	9	43,310	3.12	44,090	13,881
	12+	32,000	3.40	29,888	9,412
30	6½	44,680	3.07	46,199	14,554
	9	42,500	3.06	44,115	13,888
	12+	41,900	3.35	39,721	12,508
31	6½	40,120	3.16	40,320	12,728
	9	36,620	3.14	37,060	11,662
	12+	28,500	3.09	29,270	9,223
	13	36,620	3.12	37,279	11,737
32	7¾	49,620	3.07	51,307	16,163
	9	38,440	2.80	43,630	13,730
	12¼	51,500	3.25	50,316	15,850
	13	35,100	2.85	39,101	12,315
33	7¾	44,120	3.10	45,179	14,232
	12	42,860	2.93	46,417	14,631
	12½	43,940	3.17	44,028	13,861
34	12	44,680	2.96	47,897	15,894
	12+	48,740	3.15	49,130	15,473
35	12	35,480	3.22	34,981	11,020
	12+	45,440	3.06	47,167	14,850
36	6½	30,120	3.02	31,626	9,973
	7¾	43,220	3.03	45,251	14,264
	12¼	33,200	2.96	35,590	11,216
37	6	42,860	3.02	45,003	14,192
	7¾	35,100	3.13	35,627	11,215
	12+	37,480	3.24	36,730	11,537
38	6	32,150	2.95	34,593	10,900
	6½	30,980	2.98	32,995	10,396
	9	50,280	2.90	55,057	17,340
	12	36,620	3.23	35,997	11,338
	12+	43,580	2.97	46,543	14,673
39	9	41,800	2.97	44,642	14,110
	12	45,250	3.13	45,929	14,457
40	12	40,700	3.05	42,369	13,344
41	12	38,980	3.03	40,612	12,864
42	6	36,810	2.91	40,160	12,650
	8½	34,940	3.05	36,373	11,455
	12	36,430	2.90	39,891	12,560
43	12	43,400	3.12	44,181	13,910
	12+	40,500	3.21	40,055	12,617
	12½	53,340	3.04	55,687	17,546

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Volts per mm.
B 44	12+	45,060	2.98	47,989	15,121
	12½	47,040	2.93	50,944	16,054
45	12	43,220	3.00	45,727	14,406
	12+	44,490	2.87	49,206	15,502
46	12	44,870	3.08	46,261	14,570
	12+	51,900	3.06	53,872	16,961
	12¼	48,040	3.06	49,865	15,686
47	12	34,140	2.17	49,947	15,733
	12½	37,960	2.04	58,956	18,608
48	12	36,240	3.07	37,472	11,805
	12¼	34,460	2.89	37,837	11,924
49	6	40,500	3.01	42,687	13,455
	8½	38,280	2.95	41,189	12,976
	12	38,280	2.91	41,763	13,155
50	8½	43,400	2.85	48,348	15,228
	12	43,400	2.97	46,351	14,613
51	12	46,200	2.76	53,176	16,740
	12¼	56,800	2.68	67,308	21,194
52	12	38,280	3.06	39,735	12,510
	13	45,820	3.15	46,186	14,546
53	12	44,680	2.85	49,774	15,681
	12¼	37,160	2.91	40,542	12,770
	13	52,500	3.06	54,495	17,157
54	12	38,980	2.66	46,542	14,654
	12½	39,740	2.70	46,734	14,720
	13	40,120	2.68	47,542	14,970
55	12¼	44,680	2.83	50,132	15,788
	13	45,440	2.78	51,983	16,345
C 1	12	22,000	3.13	22,330	7,028
2	11	45,440	3.35	43,077	13,564
	12	45,440	3.20	45,076	14,200
3	7¾	30,980	3.27	30,082	9,474
	11	44,120	3.28	42,808	13,451
	12¼	46,200	3.12	47,031	14,808
4	11	36,050	2.88	39,727	12,518
	12	44,300	2.18	50,059	15,765
5	11	37,960	3.34	36,100	11,365
	12	41,100	3.22	40,425	12,764
	12+	48,300	3.00	51,101	16,100
6	11	54,600	3.22	53,836	16,956
	12¼	53,760	3.16	54,029	17,013
	12½	44,680	3.26	43,517	13,706
7	11	45,820	3.16	47,038	14,500
	12	60,060	3.77	50,571	15,931
8	12	27,300	3.25	26,672	8,400
9	12	.....	....	.....	.....
	12¼	.....	....	.....	.....
10	12	.....	....	.....	.....
11	12	35,480	3.54	31,826	10,023

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Volts per mm.
C 12	7¾	25,580	2.54	31,975	10,071
	11	43,940	2.50	55,804	17,576
	No Cone	46,200	2.65	55,343	17,434
13	11	42,300	2.44	55,575	17,374
	12½	33,820	2.32	45,166	14,577
	No Cone marked	42,100	2.60	51,404	16,192
14	11	41,100	2.76	47,306	14,891
	13	47,040	2.52	59,270	18,666
	No Cone	44,300	2.49	56,533	17,791
15	11	31,320	2.73	36,457	11,469
	12½	46,410	2.71	54,393	17,125
16	7¾	29,940	2.58	36,826	11,605
	11	37,160	2.54	46,450	14,630
	12½	55,920	2.51	70,739	22,278
17	12½	31,660	2.55	39,317	12,415
18	12	.....	....	.....	.....
	12½	.....	....	.....	.....
19	12½	.....	....	.....	.....
	13	.....	....	.....	.....
20	12½	.....	....	.....	.....
21	12½	32,600	2.47	41,923	13,198
22	13	30,300	2.63	36,522	11,521
23	12½	33,200	2.31	45,617	14,372
	13	22,680	2.61	27,579	8,690
24	12½	34,140	2.71	40,012	12,598
25	12½	28,050	2.63	33,829	10,666
26	12	.....	....	.....	.....
	13	.....	....	.....	.....
27	12	.....	....	.....	.....
	12+	.....	....	.....	.....
	13	.....	....	.....	.....
28	12+	.....	....	.....	.....
	No Cone	.....	....	.....	.....
29	12½	29,940	2.68	35,479	11,172
30	12	32,300	2.24	45,769	14,420
	12½	28,050	2.29	38,877	12,250
	13	35,100	2.36	47,245	14,877
31	12	.....	....	.....	.....
	12½	32,600	2.55	40,587	12,784
	13	32,000	2.31	43,968	13,853
32	12	25,720	2.42	33,770	10,628
	13	23,700	2.15	34,881	11,023
33	12	.....	....	.....	.....
34	12	.....	....	.....	.....
35	12	.....	....	.....	.....
	13	.....	....	.....	.....
36	12	24,720	2.39	33,828	10,343
37	12	24,210	2.73	28,180	8,872

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm	Punc. ⅛ in. Volts	Punc. Volts per mm.
C 38	13	30,640	2.35	41,395	13,038
39	13	27,300	2.29	37,838	11,921
40	12	.....	....	.....	.....
41	12	.....	....	.....	.....
42	12	28,050	2.36	37,755	11,886
	13	27,300	2.31	37,500	11,818
43	12	22,680	2.41	29,892	9,410
44	12	.....	....	.....	.....
45	12	.....	....	.....	.....
	13	.....	....	.....	.....
46	12	.....	....	.....	.....
47	12	.....	....	.....	.....
48	12	.....	....	.....	.....
49	12	22,000	2.21	31,592	9,955
50	12	.....	....	.....	.....
51	12	.....	....	.....	.....
52	12	.....	....	.....	.....
53	12	.....	....	.....	.....
54	12	.....	....	.....	.....
55	12	.....	....	.....	.....
D 1	6	.....	....	.....	.....
	12½	.....	....	.....	.....
	13	.....	....	.....	.....
2	6	29,040	2.17	42,385	13,382
	8½	28,200	2.17	41,257	13,000
	12+	32,600	2.13	48,574	15,305
3	6	31,070	2.38	41,416	13,055
	8½	31,660	2.38	42,203	13,302
	12+	28,860	2.73	33,593	10,571
4	6	29,940	2.47	38,500	12,121
	8½	31,830	2.48	40,774	12,835
	12	39,740	2.36	53,490	16,839
	12+	28,200	2.52	35,532	11,190
5	8½	33,350	2.33	45,423	14,313
	12	30,300	2.15	44,722	14,093
6	8½	33,200	2.18	48,372	15,230
	12	34,780	2.15	51,335	16,177
	13	29,400	2.35	39,620	12,510
7	8½	28,680	2.28	39,923	12,580
	12	37,160	2.42	48,791	15,351
	13	35,670	2.25	50,295	15,851
8	7¾	30,810	2.12	46,153	14,533
	12	30,810	2.32	42,148	13,280
	12½	31,510	2.22	45,059	14,194
	13	33,500	2.79	38,190	12,007
9	8½	31,660	2.28	40,071	13,886
	12	36,240	2.14	53,780	16,934
10	12+	29,220	2.41	38,512	12,124
	12½	26,680	2.30	36,818	11,600
	13	27,300	2.26	38,329	12,080

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Volts per mm.
D 11	13	.....	....	.....	.....
12	6½	34,460	2.18	50,208	15,807
	8½	28,860	2.14	42,828	13,486
	12	36,620	2.22	52,367	16,495
13	8½	39,740	2.38	52,973	16,699
	9	27,300	2.22	38,039	12,297
	12	30,300	2.13	45,147	14,225
14	12½	27,000	2.09	41,013	12,918
	6	29,940	2.21	42,994	13,547
	7¾	35,860	2.09	54,471	17,158
	8½	37,320	2.10	56,428	17,771
15	6	25,560	2.22	36,551	11,513
	7¾	30,470	2.04	47,411	14,936
	12	28,500	2.72	31,770	10,477
16	7¾	32,900	2.17	48,133	15,161
	8½	25,720	2.12	38,529	12,132
	12	36,810	2.56	45,644	14,378
	13	31,320	2.31	43,034	13,558
17	7¾	30,640	2.19	44,428	14,000
	12	30,300	2.19	33,935	13,825
	12+	32,750	2.18	47,717	15,023
	13	37,320	2.30	51,502	16,226
18	8½	29,940	2.06	46,138	14,534
	12+	33,050	2.18	48,154	15,160
	13	33,500	2.16	49,245	15,510
19	12+	31,050	2.27	43,208	13,679
	12½	34,140	2.04	53,122	16,735
	13	32,900	2.28	45,797	14,430
20	12½	.....	....	.....	.....
	13	37,320	2.76	42,955	13,522
21	6½	32,000	2.62	38,752	12,214
	8½	39,450	2.60	48,168	15,173
	12+	42,100	2.56	52,204	16,445
22	6½	26,360	2.19	38,222	12,037
	7¾	31,660	2.19	45,907	14,457
	12+	33,500	2.37	44,890	14,135
23	6	.....	....	.....	.....
	7¾	29,580	2.32	40,465	12,750
	9	.....	....	.....	.....
	12+	26,680	2.08	40,714	12,827
	13	31,660	2.27	44,261	13,950
24	8½	29,940	2.23	42,635	13,426
	12	38,980	2.29	41,358	13,037
	12+	30,300	2.36	40,784	12,398
25	12+	37,960	2.09	57,661	18,162
	12½	36,810	2.06	56,724	17,869
	13	36,620	2.27	51,195	16,132
26	12+	43,220	2.70	50,827	16,008
	13	42,860	2.75	49,460	15,585

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Vol s per mm.
D 27	12	27,900	2.68	33,002	10,411
	12+	39,740	2.60	48,523	15,245
	13	38,980	2.58	47,945	15,110
28	13	29,220	2.69	34,480	10,862
29	6	.....	....	.....	.....
	9	.....	....	.....	.....
	12	36,240	2.52	45,662	14,381
	12+	35,100	2.62	42,516	13,397
30	6	.....	....	.....	.....
	6½	.....	....	.....	.....
	12	36,620	2.48	46,910	14,766
	12+	37,960	2.71	44,472	14,007
	13	46,010	2.62	55,218	17,561
31	6½	.....	....	.....	.....
	12	36,620	3.13	37,169	11,700
	13	35,480	2.84	39,667	12,493
32	6	43,940	2.55	54,705	17,231
	11	46,200	2.49	58,951	18,554
	12	35,100	2.49	44,788	14,092
	12+	42,300	2.73	49,237	15,494
	12½	49,180	2.58	60,491	19,062
	13	39,360	2.71	46,130	14,524
33	11	27,600	2.78	31,574	9,928
	12	32,600	2.63	39,316	12,375
	12½	45,060	2.61	54,793	17,263
34	10½	29,040	2.60	35,458	11,170
	12½	36,620	2.56	45,409	14,305
	13	37,960	2.67	45,135	14,217
35	10½	.....	....	.....	.....
	12+	.....	....	.....	.....
	12½	25,720	2.87	28,446	8,961
36	6½	.....	....	.....	.....
	11	36,240	2.24	51,352	16,180
	12½	32,450	2.67	38,583	12,154
	13	39,740	2.66	47,450	14,940
37	6½	.....	....	.....	.....
	10½	26,680	2.75	30,789	9,702
	12+	28,500	2.62	34,514	10,878
	13	24,380	2.68	28,890	9,097
38	6½	.....	....	.....	.....
	10½	30,030	2.72	35,075	11,140
	13	31,660	2.79	36,092	11,348
39	10½	25,920	2.70	30,247	9,526
	12+	32,900	2.63	39,677	12,510
	12½	32,600	2.60	39,805	12,540
	13	33,820	2.83	37,941	11,950
40	10½	.....	....	.....	.....
	12½	32,600	2.83	37,846	11,520
	13	26,360	2.65	31,569	9,947

TABLE II—Continued.

No.	Cone	Total Punc. Voltage	Thickness mm.	Punc. ⅛ in. Volts	Punc. Volts per mm.
D 41	10½	.....	....	.....	.....
	12½	27,600	2.86	30,636	9,650
	13	27,000	2.63	32,562	10,266
42	6½	.....	....	.....	.....
	11	23,700	2.74	27,468	8,650
	13	.....	....	.....	.....
43	11	23,700	2.68	28,085	8,840
	12½	29,400	2.56	36,456	11,484
	13	30,640	2.66	36,584	11,519
44	11	25,230	2.96	27,047	8,524
	12½	30,120	2.70	35,421	11,192
	13	27,150	2.64	32,634	10,284
45	10½	.....	....	.....	.....
	11	.....	....	.....	.....
	12+	32,000	2.51	40,480	12,749
45	12½	34,780	2.55	43,301	13,640
	13	32,900	2.54	41,125	12,953
46	11	.....	....	.....	.....
	13	32,600	2.52	41,076	12,932
47	12½	23,700	2.64	28,487	8,977
	13	24,200	2.54	30,250	9,527
48	12½	.....	....	.....	.....
	13	.....	....	.....	.....
49	6½	.....	....	.....	.....
	10½	.....	....	.....	.....
	13	27,900	2.76	32,113	10,109
50	10½	.....	....	.....	.....
	12½	23,700	2.69	27,966	8,810
	13	22,000	2.48	28,182	8,871
51	10½	.....	....	.....	.....
	11	.....	....	.....	.....
	13	28,200	2.58	34,686	10,930
52	12½	24,760	2.67	29,440	9,273
	13	28,350	2.50	36,005	11,340
53	12½	25,060	2.69	29,571	9,316
54	12½	.....	....	.....	.....
	13	25,400	2.84	28,397	8,944
55	12½	.....	....	.....	.....
	13	27,750	2.63	33,467	10,552

Vitrification Range.

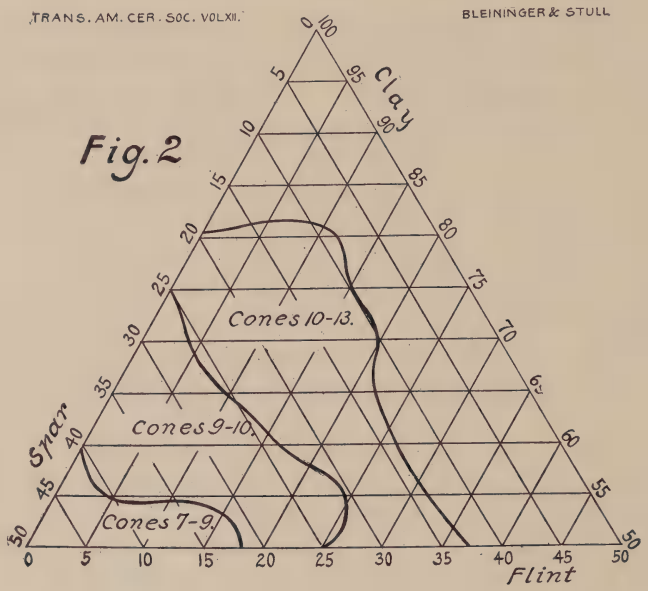
A. *Georgia Kaolin.* In Fig. 2 we find plotted three temperature areas, cone 7-9, cone 9-10, and cones 10-13. Brief inspection shows that this kaolin has a comparatively large range of compositions vitrifying below cone 10.

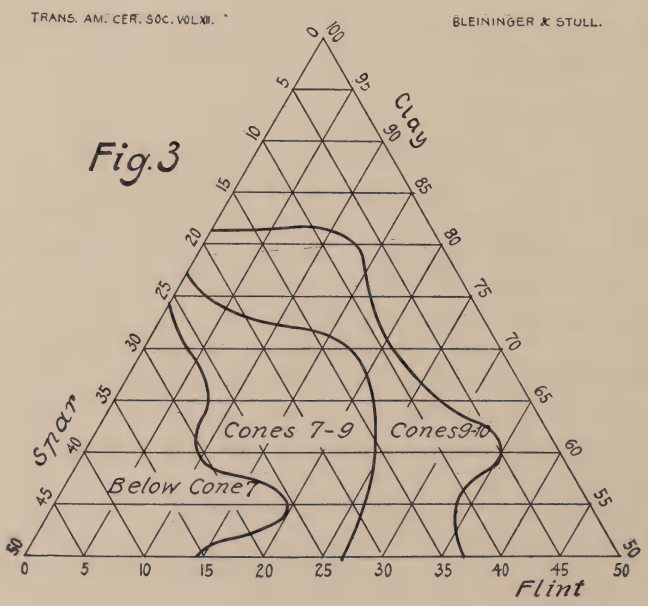
This is again illustrated by the fact that within this temperature range a feldspar content as low as 18 per cent, with 51% of clay, is shown. With a temperature corresponding to cone 13 and the same clay content, the feldspar may be cut down to 14%. The dividing line between the cone 9-10 and the 10-13 areas shows a decrease in feldspar and a corresponding increase in flint from the 25% to the 20% feldspar line.

B. *Tennessee Ball Clay,* Fig. 3. The less refractory character of this clay is indicated by the large range covered by the temperature area below cone 10. Near the 50% clay line the feldspar drops as low as 13%, and at the 60% clay line a feldspar minimum of 5% is shown at a temperature not exceeding cone 10. It is evident, therefore, that in a body the feldspar content may be the lower the greater the content of ball clay.

C. *The North Carolina Kaolin* offers quite a contrast to the last material, inasmuch as its vitrification area is quite small at temperatures up to cone 10, Fig. 4. The range is decidedly increased at the higher temperatures, and at cone 13½ it is possible to cut down the feldspar percentage to below 15%, while at cone 10 the minimum feldspar content is 23%.

D. *The English China Clay,* Fig. 5, differs from the preceding clays in that its vitrification boundaries slope far more gradually in spite of the fact that its alkali content is not greater than that of the North Carolina kaolin. With decreasing clay and increasing flint content the spar gradually diminishes until, with 50% clay, the feldspar is reduced to 15% at cone 9-10 to 5% at cone 10-11. It is evident, therefore, that this material differs considerably from similar American clays in this respect, due to its structure or fineness of grain. Its vitrification area is quite large.

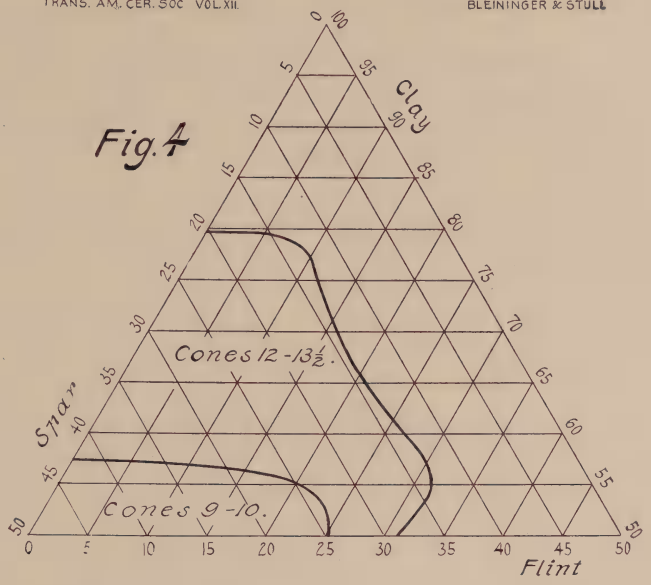

TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 2
Clay
Spar
Flint
Cones 10-13.
Cones 9-10.
Cones 7-9.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 3
Clay
Spar
Flint
Cones 7-9
Cones 9-10
Below Cone 7

TRANS. AM. CER. SOC VOL. XII.

BLEININGER & STULL

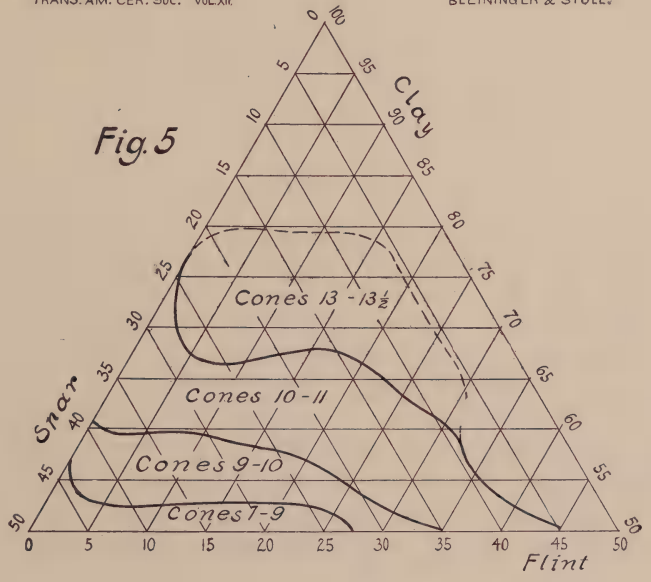
Fig. 4



TRANS. AM. CER. SOC. VOL. XII.

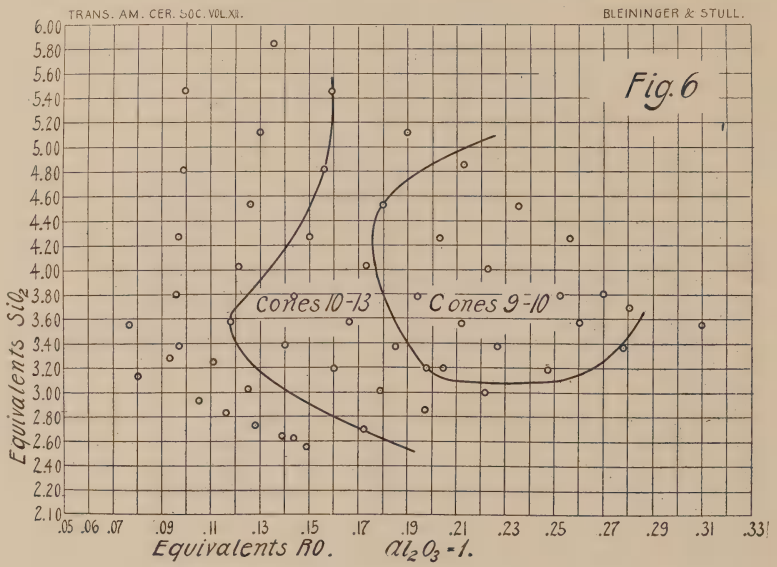
BLEININGER & STULL.

Fig. 5



Chemical Vitrification Range.

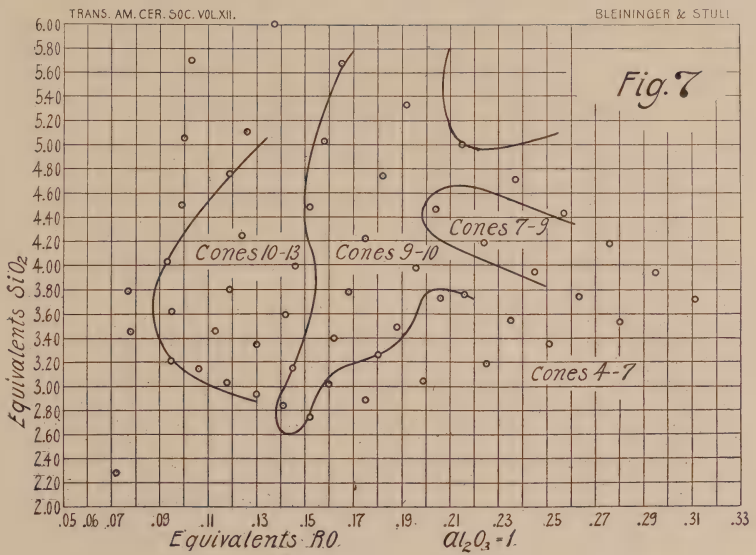
A. *Georgia Kaolin.* From this diagram, Fig. 6, we learn that the minimum and maximum limits of SiO_2 for cone 9-10 are 5.00 and 3.1 molecular equivalents. The



minimum RO for the same temperature is 0.18. At cone 13 the maximum SiO_2 is 5.42 equivalents, the minimum 2.7, while the minimum RO is practically 0.12 equivalents.

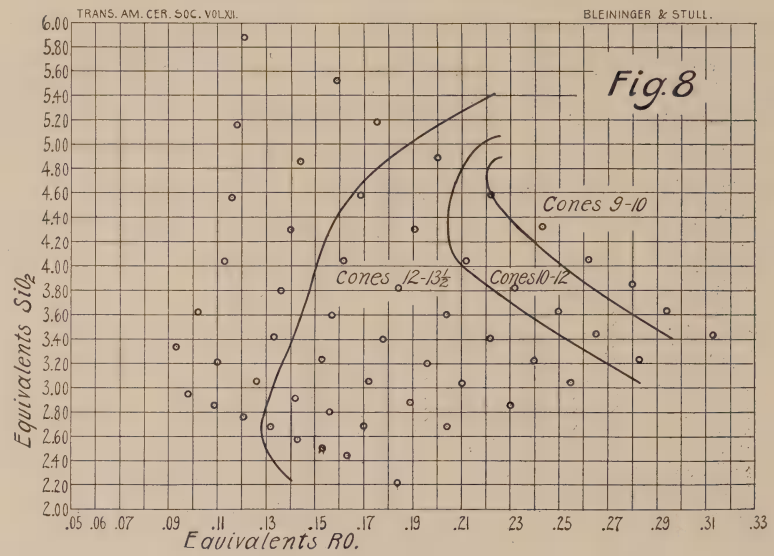
B. *The Tennessee Ball Clay* areas, Fig. 7, appear to be decidedly irregular in character. It is noted that at cone 9-10 the maximum SiO_2 is decidedly higher and the minimum quite lower than for the preceding clay, the limits being 5.7 and 2.6 respectively. It is a curious fact that the minimum RO is much less than in the Georgia kaolin, it being 0.14 at cone 10 and 0.09 at cone 13. It would seem then that the ferric-oxide which is not included in the RO is a decided factor in bringing about

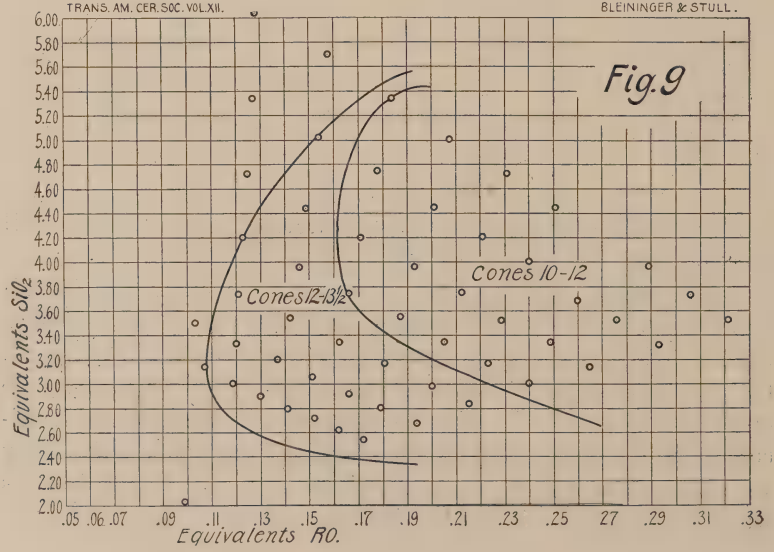
vitrification in this clay. While the total Fe_2O_3 in the ball clay is not much greater in amount than in the Georgia kaolin, it is fair to assume from the physical appearance of the former that the iron oxide is disseminated more uniformly and is more thoroughly incorporated in the clay substance. As to the peculiar shape of the vitrification areas it is evident that they permit of no generalization, and must be ascribed to differences in the heat treatment which are practically inevitable under the



usual conditions of test kiln practice, even though all possible precautions are taken.

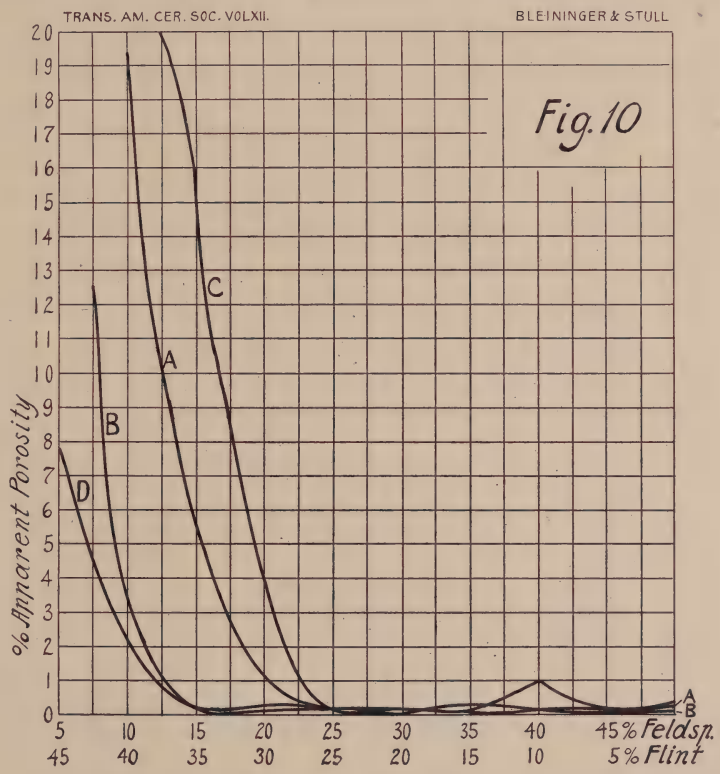
C. More symmetrical conditions prevail with the *North Carolina Kaolin* series, Fig. 8. At cone 9-10 the highest SiO_2 content in these mixtures is 4.85 equivalents, the minimum 3.40, while the minimum RO is 0.295. The cone 12-13½ area it will be observed is very large, indicating that the proper development of such a kaolin body would be obtained only at the higher temperatures, just as was shown in the triaxial diagram.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 8
Cones 9-10
Cones 12-13½
Cones 10-12
Equivalents SiO_2
Equivalents RO.
6.00 5.80 5.60 5.40 5.20 5.00 4.80 4.60 4.40 4.20 4.00 3.80 3.60 3.40 3.20 3.00 2.80 2.60 2.40 2.20 2.00
.05 .06 .07 .09 .11 .13 .15 .17 .19 .21 .23 .25 .27 .29 .31 .33


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 9
Cones 10-12
Cones 12-13½
Equivalents SiO_2
Equivalents RO.
6.00 5.80 5.60 5.40 5.20 5.00 4.80 4.60 4.40 4.20 4.00 3.80 3.60 3.40 3.20 3.00 2.80 2.60 2.40 2.20 2.00
.05 .06 .07 .09 .11 .13 .15 .17 .19 .21 .23 .25 .27 .29 .31 .33

D. Fig. 9. *The English China Clay* limits for cone 10-12 are 5.40 maximum SiO_2, 2.75 minimum SiO_2 and 0.16 minimum RO. For cones 12-13½ the maximum SiO_2 is 5.55, the minimum SiO_2 2.35, and the minimum RO practically 0.11.

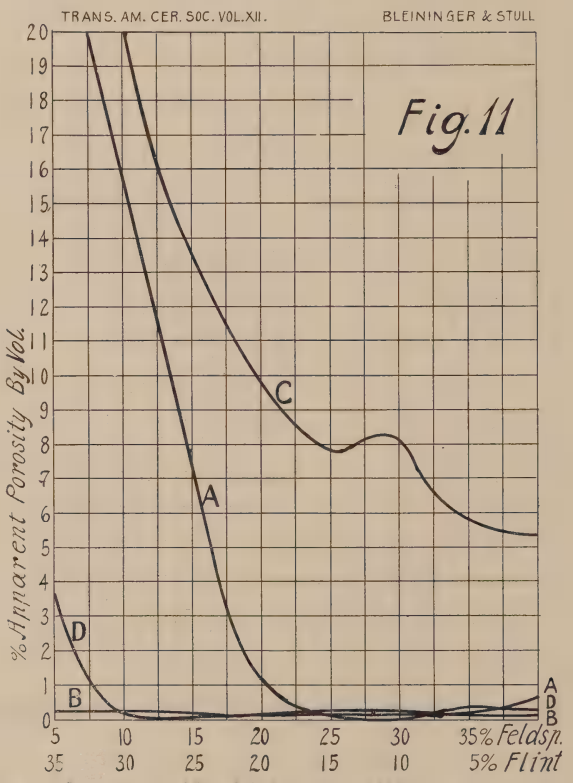
Porosity Coordinated with Feldspar-Flint Contents, —the clay being kept constant, at cone 9-10.



1. 50% *Clay, Fig.* 10. This diagram shows at once the percentages of feldspar necessary to bring about vitrification at this temperature. For the Georgia kaolin this point is about 24%, for the Tennessee ball clay less than 15%, for the N. C. kaolin 25%, and the English China clay about 15%. As far as the ball clay and the English

China clay are concerned, the feldspar-flint additions are of the nature of refractory agents. The feldspar is distinctly a flux for the N. C. kaolin but very much less so for the Georgia kaolin.

2. 60% *Clay, Cone* 9-10, *Fig.* 11. Here the true nature of the various clays is more clearly represented, and brief inspection shows that the N. C. kaolin is by far the



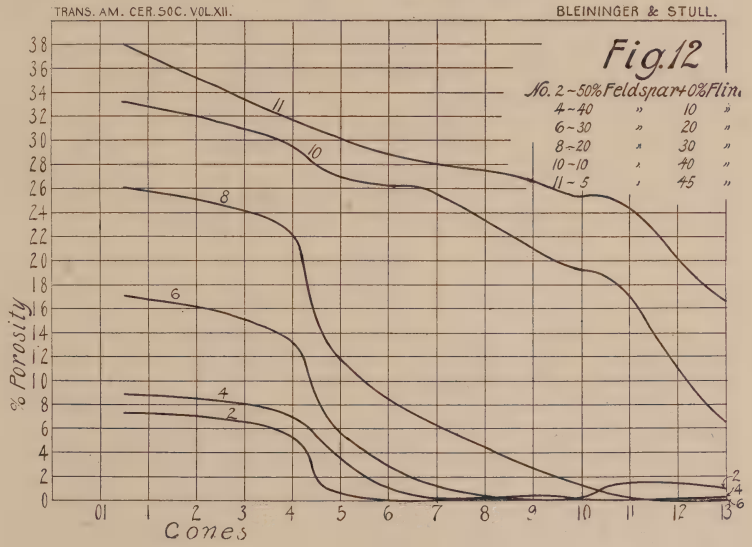
most refractory material which even with maximum amount of flux fails to produce a dense body at this temperature. With 60% clay any possible combination of spar and flint cannot bring about vitrification. The eutectic point of N. C. kaolin-spar as well as of N. C. kaolin—75% pure spar+25% flint mixture—is beyond cone 9-10.

Porosity-Temperature Diagrams.

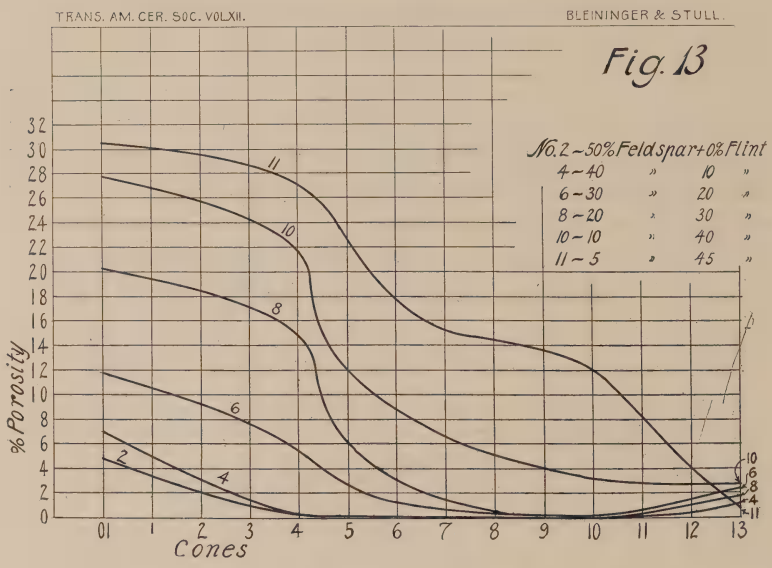
I. 50% CLAY.

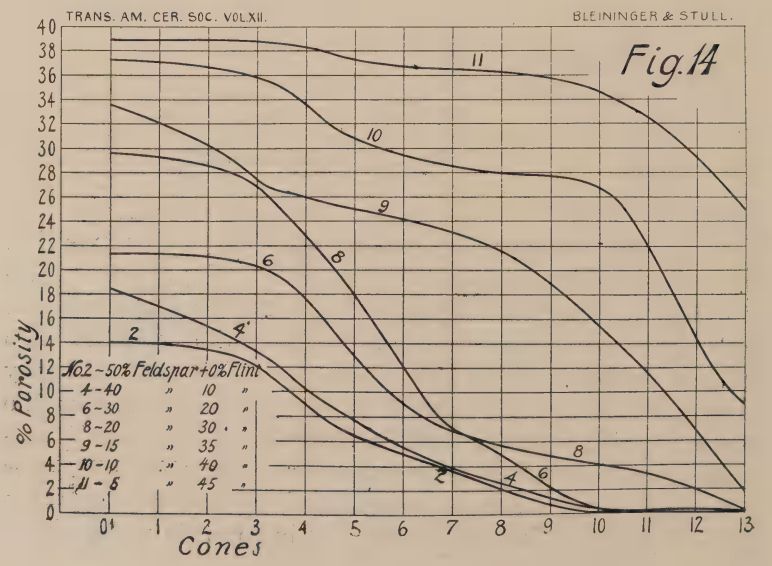
Series A, Georgia Kaolin, Fig. 12. These curves present the rate of vitrification, and we note that for the mixtures Nos. 2, 4, 6 and 8 vitrification proceeds most rapidly between cones 4 and 6, while for Nos. 10 and 11 the same action occurs only beyond cone 11.

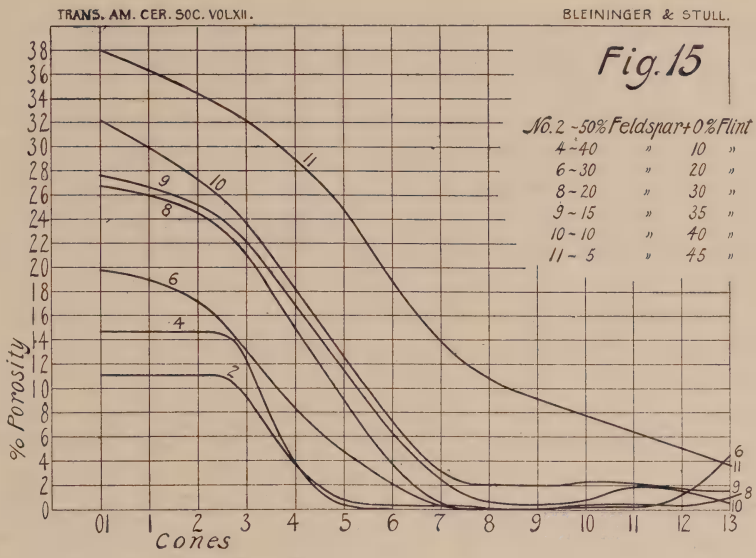
It is fair to assume then that the active fluxing magma in all bodies but No. 11 has a melting point between cones

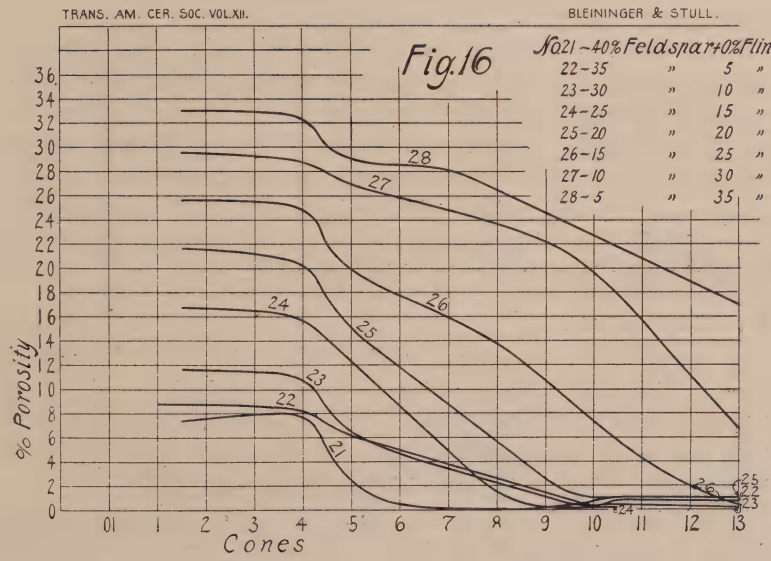


4 and 6, and it is entirely possible to find its composition by running a series of the system 0-50% clay, 50-0% feldspar+flint. From the large part of the pore space filled up during this short temperature interval it appears also that the fluxing matter has a lower viscosity than at any subsequent stage. For while at higher temperatures the total amount of the igneous solution is greater as it enriches itself in silica and alumina, the viscosity increases correspondingly, causing it to flow less readily and more liable to form a bleb structure. It is for this reason that


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 13
No. 2 ~ 50% Feldspar + 0% Flint
4 ~ 40 " 10 "
6 ~ 30 " 20 "
8 ~ 20 " 30 "
10 ~ 10 " 40 "
11 ~ 5 " 45 "
% Porosity
Cones


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 14
No 2 ~ 50% Feldspar + 0% Flint
4 ~ 40 " 10 "
6 ~ 30 " 20 "
8 ~ 20 " 30 "
9 ~ 15 " 35 "
10 ~ 10 " 40 "
11 ~ 5 " 45 "
% Porosity
Cones


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 15
No. 2 - 50% Feldspar + 0% Flint
4 - 40 " 10 "
6 - 30 " 20 "
8 - 20 " 30 "
9 - 15 " 35 "
10 - 10 " 40 "
11 - 5 " 45 "
% Porosity
Cones
01 1 2 3 4 5 6 7 8 9 10 11 12 13
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
2
4
6
8
9
10
11


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 16
No 21 - 40% Feldspar + 0% Flint
22 - 35 " 5 "
23 - 30 " 10 "
24 - 25 " 15 "
25 - 20 " 20 "
26 - 15 " 25 "
27 - 10 " 30 "
28 - 5 " 35 "
% Porosity
Cones
01 1 2 3 4 5 6 7 8 9 10 11 12 13
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
21
22
23
24
25
26
27
28

the addition of a small amount of lime is beneficial, inasmuch as it decreases the viscosity and hence reduces the above tendency.

Series B. Tenn. Ball Clay, Fig. 13. Here the conditions are very similar excepting that the greater impurity of the clay causes the curves to start at lower porosities. Like in the preceding and all subsequent series, it is evident that the fusing action of feldspar begins at quite a low temperature.

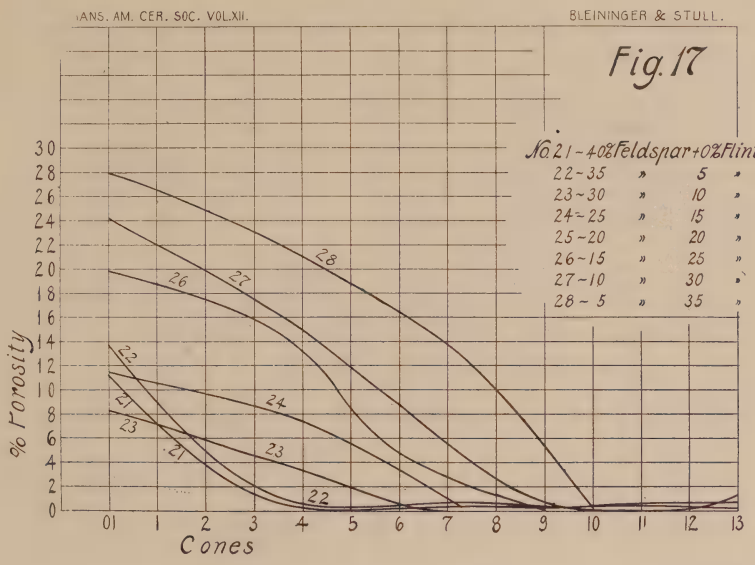
Series C. N. C. Kaolin, Fig. 14. The characteristic feature of this clay, its longer vitrification temperature range, is at once shown as is to be expected from such a comparatively coarse grained kaolin. While the Georgia kaolin in mixture No. 8 reaches vitrification between cones 11-12, the N. C. kaolin of the same mixture barely approaches the vitrified state at cone 13. This points out a useful function of this material which must not be lost sight of, its ability to hold up a clay body. The more a certain composition or shape has a tendency to deformation, the greater proportion of this kaolin can be introduced to counteract it.

Series D. English China Clay, Fig. 15. The smooth curves indicate well the character of the vitrification process. It differs from the two preceding kaolins in that it appears to bring about better vitrifying conditions, which are not too abrupt between certain points, nor does it fail to produce vitrification with a low feldspar content like that of No. 10 of A and C. Its great fineness of grain undoubtedly is a factor in this behavior.

II. 60% Clay.

Series A. Georgia Kaolin, Fig. 16. In this set of curves the same observation is made as before, viz., the highest rate of vitrification is found between cones 4 and 7 but, as is to be expected, the vitrification temperatures have been raised with the higher clay content.

Series B. Tenn. Ball Clay, Fig. 17. In distinction from the preceding clay, the vitrification temperatures are



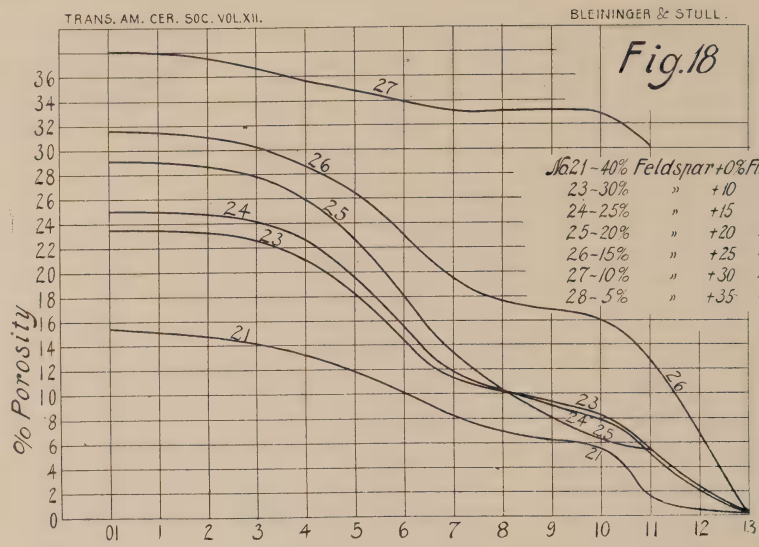
lower than with 50% mixtures, a fact to which attention has already been called above.

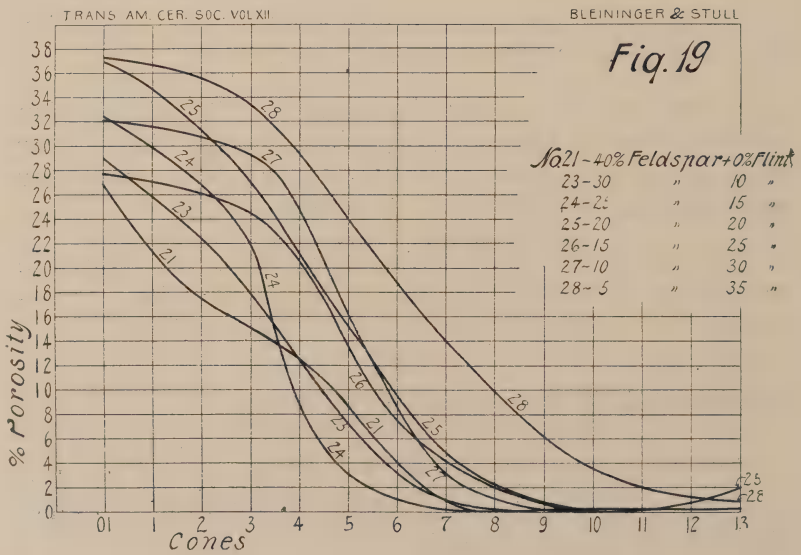
Series C. N. C. Kaolin, Fig. 18. The vitrification temperatures of these mixtures are considerably higher than in the 50% series, and the slopes of the curves far more gradual in the cone 4-7 interval.

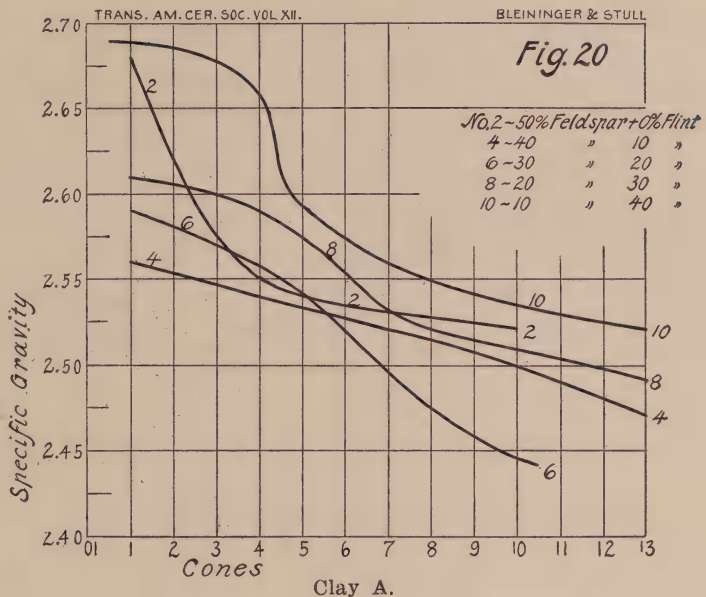
Series D. English China Clay, Fig. 19. Here no radical changes are noted though the vitrification temperatures have been shifted somewhat to the right.

Specific Gravity-Temperature Diagrams.

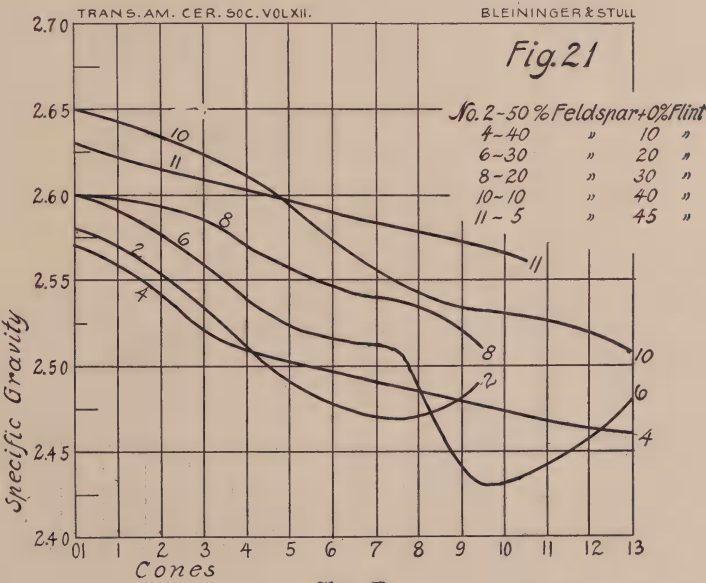
In figures 20, 21, 22, 23, 24, 25, 26 and 27 the fact that silicates undergo an increase in specific volume upon vitrification is shown clearly.


TRANS. AM. CER. SOC. VOL. XII.
BLEININGER & STULL.
Fig. 18
No 21 - 40% Feldspar + 0% Flint
23 - 30% " + 10 "
24 - 25% " + 15 "
25 - 20% " + 20 "
26 - 15% " + 25 "
27 - 10% " + 30 "
28 - 5% " + 35 "
% Porosity
01 1 2 3 4 5 6 7 8 9 10 11 12 13

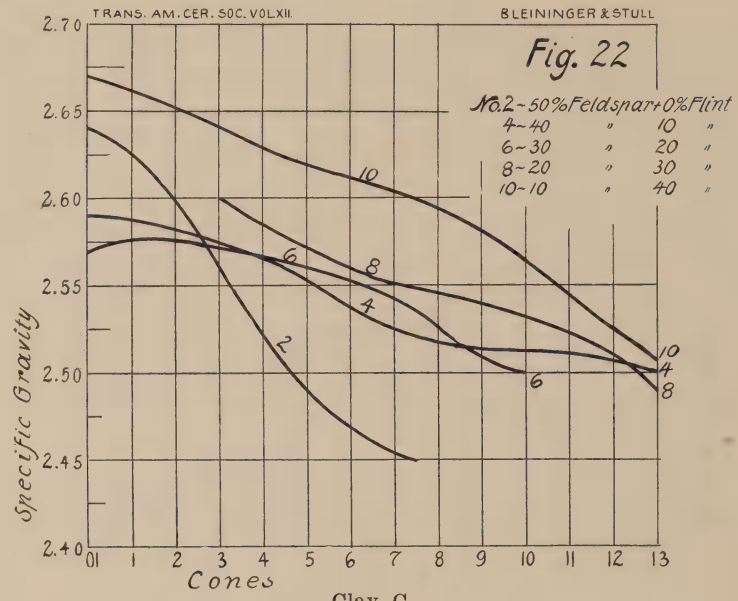

TRANS. AM. CER. SOC. VOL XII
BLEININGER & STULL
Fig. 19
No 21 - 40% Feldspar + 0% Flint
23 - 30 " 10 "
24 - 25 " 15 "
25 - 20 " 20 "
26 - 15 " 25 "
27 - 10 " 30 "
28 - 5 " 35 "
% Porosity
Cones
01 1 2 3 4 5 6 7 8 9 10 11 12 13


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 20
No. 2 ~ 50% Feldspar + 0% Flint
4 ~ 40 " 10 "
6 ~ 30 " 20 "
8 ~ 20 " 30 "
10 ~ 10 " 40 "
Specific Gravity
2.70
2.65
2.60
2.55
2.50
2.45
2.40
01 1 2 3 4 5 6 7 8 9 10 11 12 13
Cones

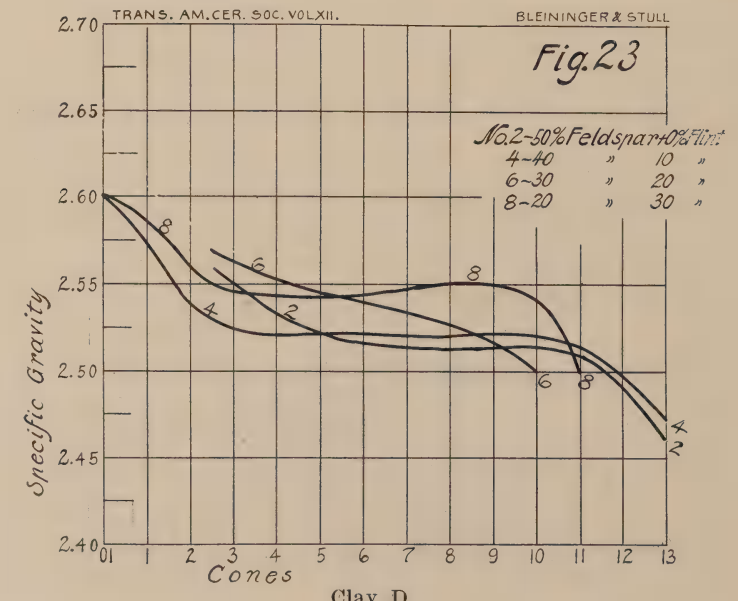
Clay A.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 21
No. 2 - 50 % Feldspar + 0% Flint
4 - 40 " 10 "
6 - 30 " 20 "
8 - 20 " 30 "
10 - 10 " 40 "
11 - 5 " 45 "
Specific Gravity
2.70
2.65
2.60
2.55
2.50
2.45
2.40
01 1 2 3 4 5 6 7 8 9 10 11 12 13
Cones

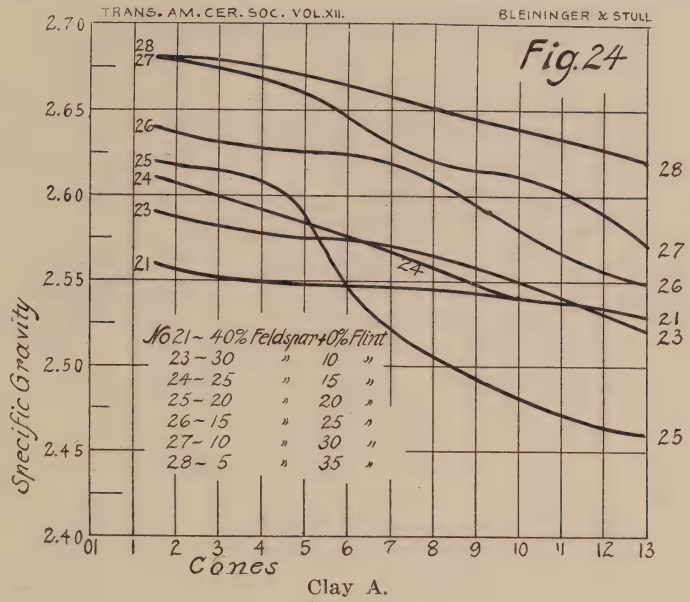
Clay B.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 22
No. 2 - 50% Feldspar + 0% Flint
4-40 " 10 "
6-30 " 20 "
8-20 " 30 "
10-10 " 40 "
Specific Gravity
Cones
2.70
2.65
2.60
2.55
2.50
2.45
2.40
01 1 2 3 4 5 6 7 8 9 10 11 12 13

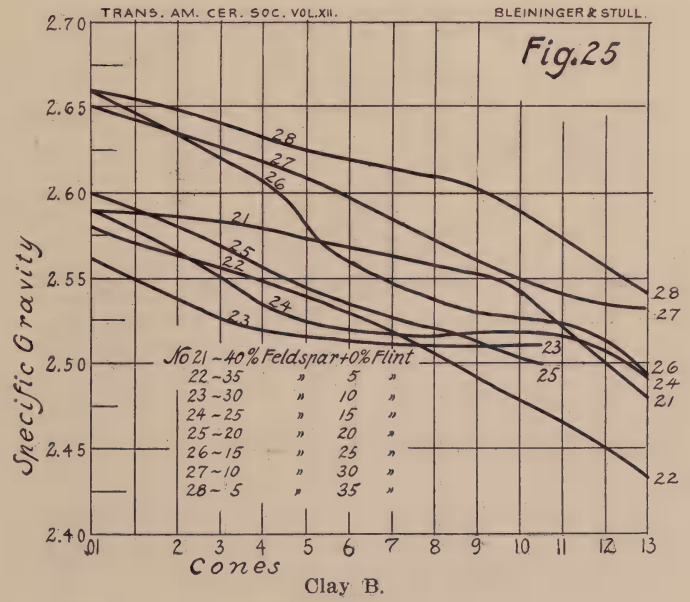
Clay C.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 23
No. 2 - 50% Feldspar + 0% Flint
4-40 " 10 "
6-30 " 20 "
8-20 " 30 "
Specific Gravity
Cones
2.70
2.65
2.60
2.55
2.50
2.45
2.40
01 1 2 3 4 5 6 7 8 9 10 11 12 13

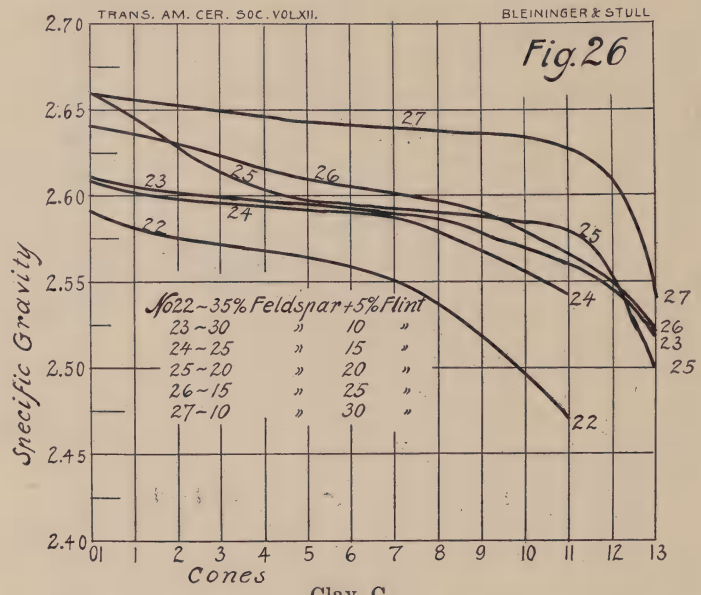
Clay D.


TRANS. AM. CER. SOC. VOL. XII.
BLEININGER & STULL
Fig. 24
Specific Gravity
Cones
No 21 ~ 40% Feldspar + 0% Flint
23 ~ 30 " 10 "
24 ~ 25 " 15 "
25 ~ 20 " 20 "
26 ~ 15 " 25 "
27 ~ 10 " 30 "
28 ~ 5 " 35 "

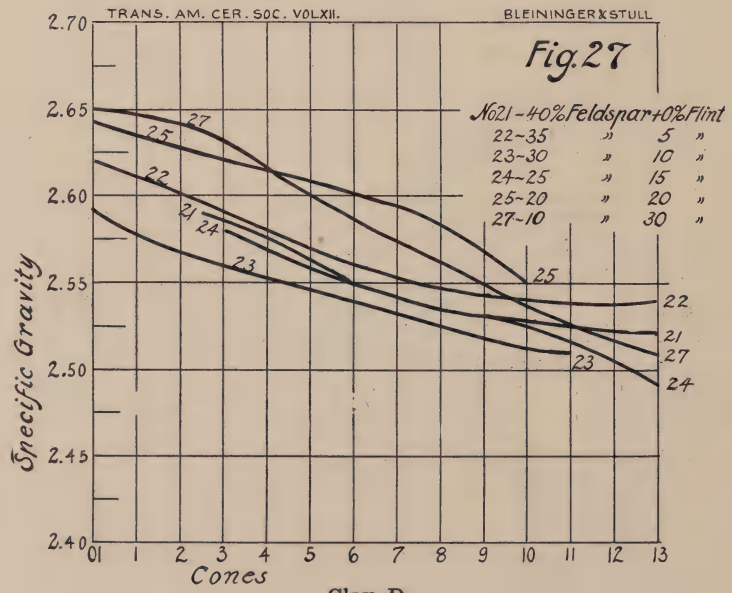
Clay A.


TRANS. AM. CER. SOC. VOL. XII.
BLEININGER & STULL
Fig. 25
Specific Gravity
Cones
No 21 ~ 40% Feldspar + 0% Flint
22 ~ 35 " 5 "
23 ~ 30 " 10 "
24 ~ 25 " 15 "
25 ~ 20 " 20 "
26 ~ 15 " 25 "
27 ~ 10 " 30 "
28 ~ 5 " 35 "

Clay B.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 26
Specific Gravity
2.70
2.65
2.60
2.55
2.50
2.45
2.40
01 1 2 3 4 5 6 7 8 9 10 11 12 13
Cones
No 22 - 35% Feldspar + 5% Flint
23 ~ 30 " 10 "
24 ~ 25 " 15 "
25 ~ 20 " 20 "
26 ~ 15 " 25 "
27 ~ 10 " 30 "
22
23
24
25
26
27

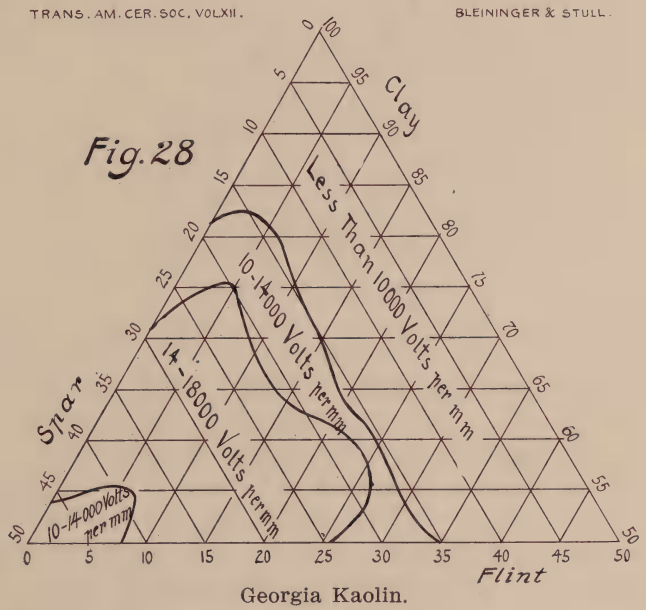
Clay C.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 27
Specific Gravity
2.70
2.65
2.60
2.55
2.50
2.45
2.40
01 1 2 3 4 5 6 7 8 9 10 11 12 13
Cones
No 21 - 40% Feldspar + 0% Flint
22 ~ 35 " 5 "
23 ~ 30 " 10 "
24 ~ 25 " 15 "
25 ~ 20 " 20 "
27 ~ 10 " 30 "
21
22
23
24
25
27

Clay D.

DI-ELECTRIC BEHAVIOR.

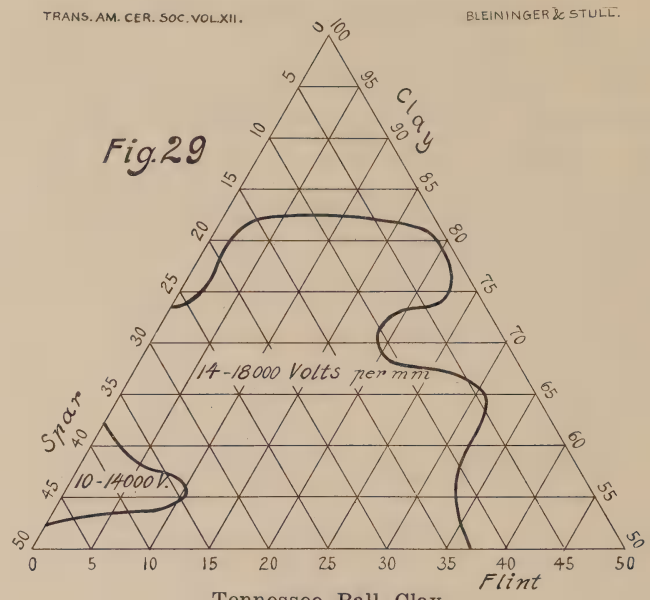
In Table II the voltages required to puncture the test pieces are compiled, together with the burning temperatures in cones. The voltages have been arranged in three groups which are: Less than 10,000 volts per mm; from 10,000-14,000 volts per mm., and from 14,000-18,000 volts per mm. These groups are shown in the triaxial composition diagrams, Figs. 28, 29, 30 and 31. Of each composition the specimen showing the highest resistance was se-


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL.
Fig. 28
Clay
Spar
Flint
Less Than 10000 Volts per mm
10-14000 Volts per mm
14-18000 Volts per mm
10-14000 Volts per mm
0 5 10 15 20 25 30 35 40 45 50
100 95 90 85 80 75 70 65 60 55 50

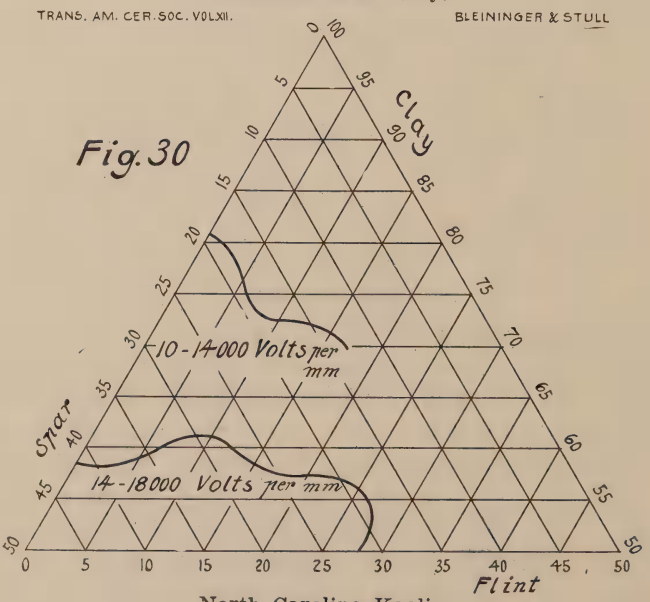
Georgia Kaolin.

lected without regard to the burning temperatures. The di-electric punctures seemed to locate flaws in the body structure with accuracy, and frequently the break would occur some distance away from the electric contact, through some jiggering defect. Results, in which puncture was evidently due to a flaw, were rejected.

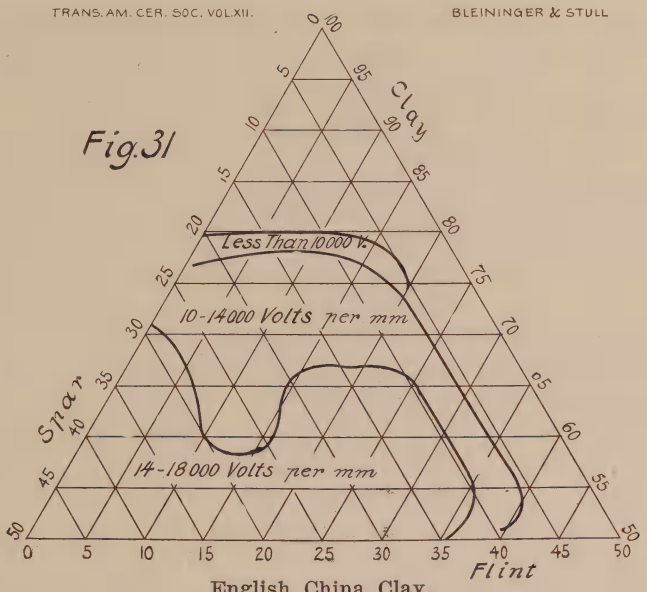
On comparing the di-electric strength diagrams it is found that the maximum voltage group is by no means restricted to a short range in composition but covers a



Tennessee Ball Clay.



North Carolina Kaolin.


TRANS. AM. CER. SOC. VOL XII.
BLEININGER & STULL
Fig. 31
Clay
Spar
Flint
Less Than 10000 V.
10-14000 Volts per mm
14-18000 Volts per mm
0 5 10 15 20 25 30 35 40 45 50
100 95 90 85 80 75 70 65 60 55 50

English China Clay.

large area, in each case roughly proportional to the vitrification area. If this electrical test is acceptable, of which the writers are not certain, since they have no familiar knowledge of insulator testing, it would seem then that any well vitrified body, free from mechanical and burning flaws, irrespective of composition, would be suitable for insulation work as far as electrical resistance is concerned. It is therefore more a matter of obtaining sound vitrification than of a certain composition. The proper selection and combination of the clays for best mechanical manipulation, proper drying and normal burning and vitrification are the main points to be considered. In this respect it is evident that much can be done if the drying and burning behavior of each clay is thoroughly understood. With a mixture, for instance, of Georgia kaolin, North Carolina kaolin, and Tennessee ball clay it would be possible to meet practically every condition and by adjusting the amount of the coarser grained materials, the drying and burning behavior could be regulated satisfactorily. The

practice of the white ware potter to depend upon three or four materials for the introduction of his clay substance is a wise one, provided a proper balance is maintained between clays of the opposite type.

What has been said regarding the di-electric behavior of porcelains at atmospheric temperatures does not, of course, apply to more elevated temperatures. The electrical resistance of porcelain rapidly decreases with increasing temperature, and at the same time the composition becomes a more and more important factor. Thus a high feldspar porcelain may be an excellent nonconductor at ordinary temperature, but might break down utterly at a temperature of several hundred degrees C.

Owing to the fact that graphic presentation has been employed throughout, the facts found are more clearly shown by the diagrams than can be summarized in words. The fact that feldspar is a solvent and does not react chemically with the clay substance is again brought out clearly, as well as the observation that this mineral begins this dissolving action at a low temperature. It was shown also that the structure and fineness of grain of the clays incorporated in a body have a decided influence upon the vitrification process. In one case (Tennessee ball clay) the feldspar-flint mixture even behaved as a refractory constituent in the 50% clay body. From this it follows that the feldspar content required depends upon the individual clays employed and not upon the total content of so-called clay substance. In this way it may be possible to cut down the percentage of feldspar by changing one or more of the clays.

Attention was called to the fact that the *rate* of vitrification of the various bodies was not constant, but showed an acceleration, usually between cones 4-7. This was ascribed, in part, to the lower viscosity of the resulting fusible component at these temperatures.

The English China clay showed a more uniform rate of vitrification and a greater range than the two American kaolins.

Vitrification is accompanied by increase in the specific volume. The work failed to show any regular relation between feldspar content and burning temperature on the one hand and the development of vesicular structure on the other.

The electrical resistance seems to depend more upon sound vitrification and good mechanical structure than chemical composition, excepting, of course, insofar as the latter governs the vitrifying behavior.

The thanks of the writers are due to Professor C. W. Rolfe, Director of the Department of Ceramics, University of Illinois, for having granted the funds necessary for this work, and to Messrs. W. S. Williams, A. E. Williams, S. B. Radcliffe and R. K. Hursh for their careful work and faithful cooperation.

DISCUSSION.

Mr. Purdy: I notice that you plot your results on basis of chemical composition, rather than mineralogical constitution. Are you more willing to base your deduction on chemical composition than on mineralogical constitution? In other words, would it not have been more logical procedure to have plotted your data with the minerals as variants rather than the oxides of which the minerals are comprised?

Mr. Bleininger: The results are referred both to the chemical composition (from the analyses) and to the percentage composition of the three constituents. No attempt has been made to get at the mineral composition, i. e., content of clay substance, feldspar and quartz in their theoretical relations.

Mr. Purdy: In the first place, we do not know the exact mineralogical constitution of the commercial kaolins and feldspars. In the second place, such breaking down of originally added mineral compound, as for instance, kaolinite to form sillimanite will not take place in the vitrified portion at the same temperature nor at the same rate

as they would if heated alone, i. e., without admixture of other minerals. The transition from the unstable Al_2O_3 $2\,SiO_2$ to the stable $Al_2O_3 : SiO_2$ occurs in porcelains much earlier than it would in pure kaolinite.

Then again, the reversible transition from quartz to tridimite varies in rate with variation in viscosity, etc., of the molten solution in which the free silica is dissolved. In some porcelain mixtures I doubt if there is a complete reversal from tridimite to quartz.

It is a fact, however,—and Professor Bleininger will agree with me in this—that the only decided chemical alteration taking place in vitrifying porcelain is the breaking down of kaolinite to the more stable form—sillimanite. While it is a fact also that this transformation or breaking down takes place in a fusion at much lower temperature than it otherwise would, the researches that Mr. Watts quoted last year demonstrated that it was a very sluggish transformation. This means that in a vitrified porcelain, sillimanite is formed so slowly that it does not progress very far under the normal burning condition prevailing in porcelain factories.

We may not be in position to speculate as to the exact constitution of the vitrified porcelain, yet we do know as much, if not more, about the constitution of it in this condition than we possibly can of it in the unburned condition.

Mr. Bleininger: I do not agree with Professor Purdy in all he says. In fact, I believe we are still far off from knowing what takes place during vitrification and fusion in systems involving at least three minerals, under conditions far from equilibium and influenced by such factors as difference in fineness of grain, rate of heating and cooling, etc. Again there comes in the difficulty of determining the minerals composing the clay, feldspar and quartz, with any degree of accuracy. Surely, the structure of such clays as the North Carolina and Georgia kaolins is not differentiated by the present methods of mineral analysis

or mineral computation. That we have realized the differences caused by the uses of different clays is shown by the very aim of this work where we have combined the same feldspar and quartz with four different clays. I see hence no objection to referring the results to percentage composition and chemical formulæ. The latter at least are based upon positive facts, the chemical composition obtained by analysis. As soon as we have methods available for mineral analysis of reasonable accuracy, which do not depend upon an insufficient technique or theoretical calculation, I am sure they will be used.

Mr. Purdy: What I have in mind is this. If you should make up the body by molecular formula based on chemical analysis of the materials, introducing your K_2O, etc., from different sources, would you have the same results? In other words, would you base a consistent argument or expect constant result by blending wholly on basis of chemical composition? Does not the sort of minerals you use have very large effect?

Mr. Bleininger: I do not deny that the mineral structure is of importance, but the finer the constituents of a body are ground the less important does the initial mineral composition become. Thus recent work has shown that a good porcelain body was obtained from a mixture of pure silica, pure alumina and alkali. Given fine enough grinding and long enough burning and the initial mineral structure will be wiped out. However, in most of our American bodies the initial structure persists—a fact which is well realized. What I wish to bring out is the fact that the usual calculated mineral composition and that obtained by the rational analysis is inaccurate and based upon conceptions which are not in accord with facts. Why not then be content with the chemical composition as given by analysis? As to the final mineral composition of a body very little is known. We know for instance that sillimanite is formed in porcelains at certain temperatures, but to use the amount of this mineral present as a criterion of the value of a body seems far fetched.

Mr. Purdy: The point in question might be made by taking this case. Suppose we have the potash introduced through a viscous medium like feldspar, that is, viscous in the molten state, or through the medium of mica, or any other silicate which contains alkalies? We could get different results, or we might get the same results, with the same chemical composition. It depends upon the viscosity of the medium through which the oxides are added whether the reaction is going to come to equilibrium or not, and the mineralogical constitution, both initial and final, is in my estimation much more important than the simple analysis of the body. We have tried some of those things this year and found that it was far more logical, or our data were followed far more easily on the simple mineralogical basis, than on basis of chemical composition. We have come to the conclusion, therefore, that it is foolishness to write a molecular formula of the body as we do of glazes, because we have produced different bodies on the same formula.

If you mix potash, alumina, and silica in the same proportion as in pure feldspar, and then frit the mix, you will obtain feldspar. No one questions that. Day and Allen did that very thing, but they had to fuse and refuse the mass many times before they obtained any large percentage amount of feldspar from the mix used. If a feldspar be thus made and used as a constituent in porcelain, may I ask would it not be feldspar still, although synthetically prepared? Watts imitated Cornwall stone thus, but he calcined his synthetic mix before attempting its use. You cannot add K_2O, Al_2O_3 and SiO_2 as such and make a porcelain that would be like one of same composition but made from commercial feldspar, etc.

The researches of Seger, Mellor, Simonis, Berdel, and of Shepherd and Rankin, leave but little if any doubt that fusion in porcelain is not attended by chemical reaction between the mineral components, and that the only chemical phenomena noted is the formation of sillimanite from kaolinite.

Mr. Bleininger: It will be noticed that the results of the work, porosity and di-electric strength, are not referred to the chemical composition but to the percentages of clay, feldspar and quartz. The chemical composition has been used for the purpose of classification for which purpose I maintain that it is closer to the facts than any hypothetical mineral composition.

Mr. Purdy: There is one other point in that connection. Of course, in the bodies we do not completely fuse the mix. Such a procedure would result in distorted ware. Synthetically made porcelain, unless made from fritted or calcined material, will not be of the same sort as those porcelains you have exhibited here. I have seen porcelain glazes attempted synthetically. They were failures. The same would be true in porcelain bodies. While working in a floor tile factory, I attempted the duplication of certain French porcelain on basis of chemical composition. I failed. The same can be said for any ceramic body and nearly all of the alkaline earth glazes.

But there is one other point, feldspar in large quantities produces a vesicular structure. Have you determined the effect of bleb structure in di-electric strength? I noticed the high strength was in the high feldspar bodies but the maximum feldspar was only 50%.

Mr. Bleininger: The determinations of the true specific gravities were made for the primary purpose of getting at the "bleb" structure, but we were grievously disappointed in finding that the porosity curves expressing the enclosed pore space were far from consistent. Roughly, the bleb space increased with the content of feldspar, but it seemed that the variations in physical structure were an important factor. Thus the amount of water used and the manipulation evidently brought about fluctuations in the volume of enclosed poral space. We regret exceedingly that we failed to show any consistent relation in this direction.

CONCERNING THE POSITION OF BORON IN THE GLAZE FORMULA.

BY

FELIX GUSTAV SINGER, Bunzlau, Germany.
(*Translated by Arthur S. Watts*)

INTRODUCTION.

In his treatise[1] Seger classes boric acid and silicic acid together, in which connection he claims that the replacement of one equivalent of silicic acid by boric acid reduces the melting point of the glaze without affecting the chemical equilibrium of the remainder of its composition. The two acids SiO_2 and B_2O_3 are placed by Seger as opposed to the RO bases, and also the Al_2O_3. This treatise forms the basis for the belief universally prevailing in the ceramic world, that B_2O_3 possesses the same characteristics in the glaze-formula as SiO_2, and that these two substances hence belong in the same column in the glaze-formula. This view is held by the writers not only of the larger reference works and hand-books, but also of the newer theoretical ceramic text books.[2]

Seger's views were attacked by Ross C. Purdy and Harry B. Fox in their treatise on "Fritted Glazes,[3] in which they conclude that the radical B_2O_3 and Al_2O_3 are analogous in glazes, and possess entirely different characteristics from the SiO_2. The same opinion is reached by C. F. Binns in his article "The Function of Boron in the Glaze Formula,[4] in which he asserts that B_2O_3 possesses direct basic characteristics.

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[1] Uber Glazuren-Fehler und deren Ursachen.

[2] Pukall, Keramisches Rechnen; Jackson, A Text-book on Ceramic Calculations, &c.

[3] Trans. Am. Cer. Soc., Vol. IX, p. 95.

[4] Trans. Am. Cer. Soc., Vol. X, p. 158.

Stimulated by these investigations, I undertook the following research in the hope of assisting in the solution of this question. In the first place, I do not attempt to prove that B_2O_3 possesses either acid or basic characteristics in glazes, but confine myself to the discussion of the similarity of its manner of working with that of the Al_2O_3 and the other analogous sesquioxides.

I first desire to call attention to the similarity of the two elements B_2O_3 and Al_2O_3 as regards their location in the periodic system, their similar atomic values, and their similar combining forms, and also the similar peculiarities or characteristics of their corresponding combination forms, especially in molten bodies. The two sesquioxides B_2O_3 and Al_2O_3 belong to the small class which possesses the property of solidifying as glass-like and amorphous bodies from the molten condition. However, while B_2O_3 melts relatively easily, the melting-point of Al_2O_3, corresponding to its higher molecular weight, belongs to an unsimilar, higher temperature, i. e., oxy-hydrogen flame.

The borates are more difficultly fusible than boric acid, while correspondingly the aluminates have not, up to the present time, been melted alone. However, these substances do attain glass-like characters to a high degree, as is indicated by the fact that Al_2O_3 dissolves in other silicate glasses. However, in this event, it hinders glassification, exactly the same as the boron-trioxide noted by Purdy and Fox.

The same opinion is expressed by Zulkowski,[5] where he speaks of the possible existence of the pyro-borates as analogous to the pyro-aluminates. Moreover, the two sesquioxides, Al_2O_3 and B_2O_3, display the same favorable influence upon the durability of glass. This is illustrated in the following curves by R. Schaller.[6] In interpreting them, Schaller reaches this conclusion: "In the glass industry, not only B_2O_3 but also Al_2O_3 *and the analogous*

[5] "Über die Konstitution des Glases," "Die Chemische Industrie," 1899, No. 13, page 280.

[6] Sprechsaal, No. 42, 1909, page 616.

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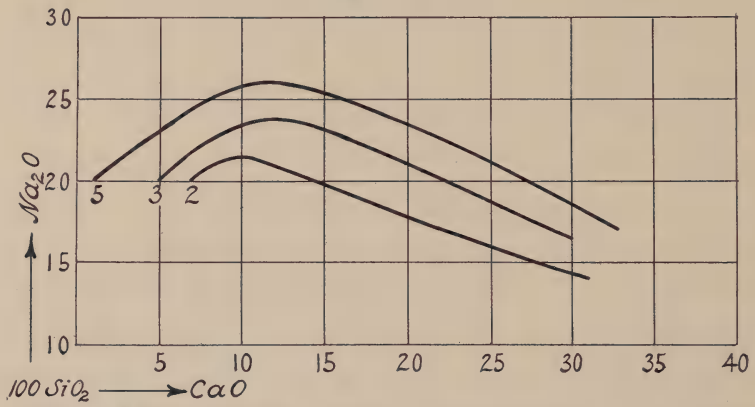
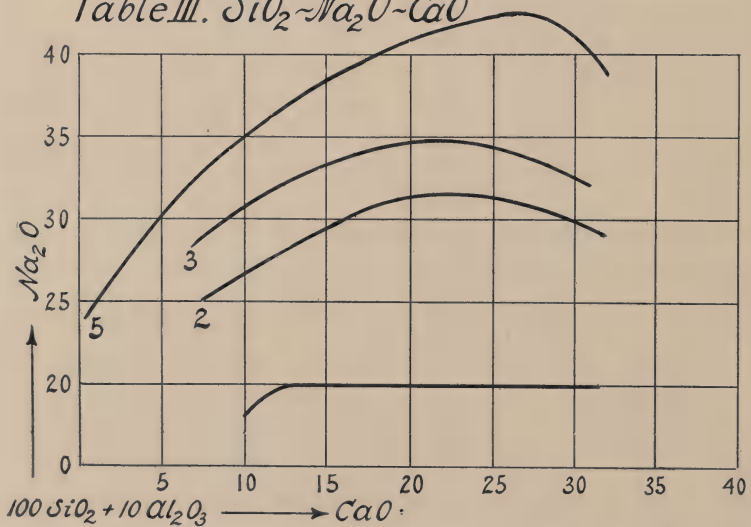
Table II. SiO_2 - Na_2O - CaO



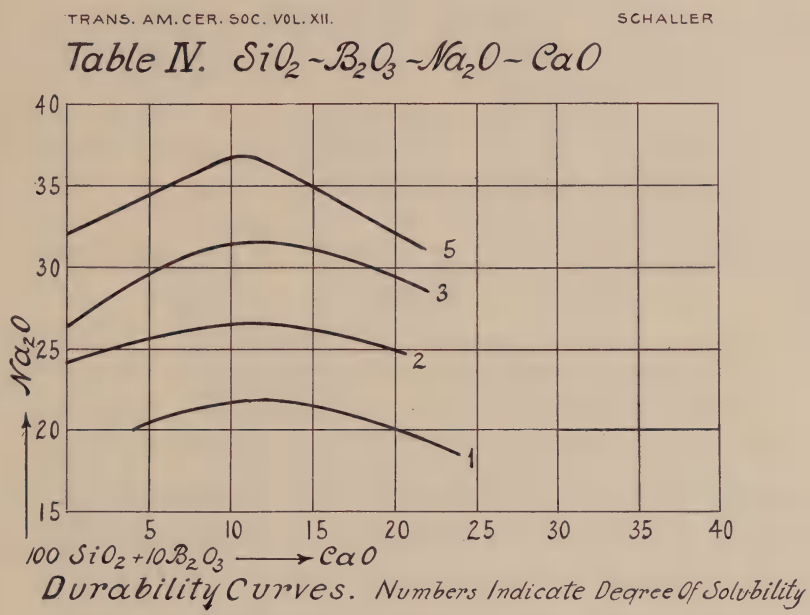
Durability Curves. Numbers Indicate Degree of Solubility

TRANS. AM. CER. SOC. VOL. XII. SCHALLER

Table III. SiO_2 - Na_2O - CaO



Durability Curves. Numbers Indicate Degree of Solubility



sesquioxides, Fe_2O_3 and Mn_2O_3 are claimed to be *acids."* This opinion was based upon the above mentioned treatise by Zulkowski.[7]

The following research will deal especially with the investigation of the seven topics mentioned below:

(A) Substitution of Al_2O_3 and B_2O_3 in fritted matt-glazes and investigation of the resulting changes.

(B) Comparison of the influence of Al_2O_3 and B_2O_3 upon cobalt-blue glazes.

(C) Comparison of the influence of Al_2O_3 and B_2O_3 upon turquoise-blue copper glazes.

(D) Comparison of the influence of Al_2O_3 and B_2O_3 upon red and green under-glaze colors.

(E) Direct test of boro-silicate fusions as to their acidity or basicity.

(F) Production of crystallized, mutually isomorphous silicates of Al_2O_3, V_2O_3, Mn_2O_3, Fe_2O_3, Co_2O_3 and B_2O_3.

(G) Similar color influence of Al_2O_3 and B_2O_3 in artificial crystalline silicates and corresponding similarity with glazes.

A. Replacement of Al_2O_3 by B_2O_3 in Unfritted Matt Glazes.

In his article "Types of a Matt Glaze for Cone 2-4," Orton[8] gives a curve by which is shown the necessary basicity for good matt-glazes. Dr. W. Pukall had previously stated that on fine stoneware at cone 7 good matt-glazes were obtainable when the oxygen-ratio (Al_2O_3 being reckoned with the RO as a base) of the bases to the acids was 1:2. This ratio can be located in the Orton curve and therefore serves as a confirmation of it. With this fact as a basis, I investigated the influence of the introduction of boric acid in the place of aluminum oxide in matt glazes; i. e., whether in addition to the natural lowering of the melting point of the glaze, the B_2O_3 acts as an acid like SiO_2, as Seger claims, or whether it is to be placed in the column of the sesquioxides, R_2O_3, and acts in a manner analogous to Al_2O_3. I attach special importance to the fact that the constitution of the glaze remains the same, i. e., that the introduction of the B_2O_3 is not effected in the customary form of a fritt, but by means of calcium-borate, by which the character of the raw glaze was not changed.

After this investigation was nearly completed I learned of the statement made by Binns in the discussion of matt glazes and the influence of boron on them.[9]

In the following experiments, which were carried out entirely independent of the above statement, the author

[7] See 5.

[8] Trans. A. C. S., Vol. X, pp. 547-582.

[9] Trans. A. C. S., Vol. XI, p. 171.

does not desire to encroach upon Binns' work, but is able to confirm his statements.

I started with the following proved matt glaze

$$\text{A 1} \quad \left.\begin{matrix} 0.7\ CaO \\ 0.2\ K_2O \\ 0.01\ MgO \end{matrix}\right\} \quad 0.6\ Al_2O_3 \quad 2.8\ SiO_2$$

O. R. = 1:2

BATCH WEIGHTS.

Feldspar	11.18
Magnesite	.84
Zettlitz Kaolin	10.36
Flint from Hohenbocka sand	4.83
Marble, pulverized	7.09
	34.30

and introduced boron trioxide in the form of calcium borate ($CaO\ B_2O_3$) by increasing substitutions for Al_2O_3. If B_2O_3 has the same acid functions as SiO_2, it will, when introduced into the above glaze in the place of Al_2O_3, completely change the oxygen ratio, which in the above A 1 glaze is 1:2. The glaze will become more acid, with a lower melting point, and the oxygen ratio of bases to acids will attain values by which otherwise no matt glazes would be obtained. However, if one classes the B_2O_3 with the sesquioxides, R_2O_3, for which it is introduced, the oxygen ratio is not changed although the melting point is lowered.

$$\text{A 2} \quad \left.\begin{matrix} .7\ CaO \\ .2\ K_2O \\ .1\ MgO \end{matrix}\right\} \quad \left.\begin{matrix} .55\ Al_2O_3 \\ .05\ B_2O_3 \end{matrix}\right\} \quad 2.8\ SiO_2$$

O. R. 1 : 2 if B_2O_3 is a base
O. R. 1 : 2.26 if B_2O_3 is an acid

BATCH WEIGHTS.

Feldspar	11.18
Magnesite	.84
Zettlitz Kaolin	9.06
Flint from Hohenbocka sand	5.44
Calcium borate	.63
Marble, pulverized	6.51
	33.66

At the temperature of Seger cone 4-5, this gives a beautiful matt glaze.

The following five experimental glazes and their character after fusion are shown in the following table:

Number of the Glaze	Forumla			Oxygen Ratios		Cone at which the glaze matures	Character of glaze produced
	RO	R_2O_3	SiO_2	If B_2O_3 be basic	If B_2O_3 be acid		
A 3..	0.7 CaO 0.2 K_2O 0.1 MgO	0.5 Al_2O_3 0.1 B_2O_3	2.80	1:2	1:2.480	4	good matt glaze
A 4..	0.7 CaO 0.2 K_2O 0.1 MgO	0.45 Al_2O_3 0.15 B_2O_3	2.80	1:2	1:2.766	3—4	good matt glaze
A 5..	0.7 CaO 0.2 K_2O 0.1 MgO	0.40 Al_2O_3 0.20 B_2O_3	2.80	1:2	1:3.090	2—3	good matt glaze
A 6..	0.7 CaO 0.2 K_2O 0.1 MgO	0.30 Al_2O_3 0.30 B_2O_3	2.80	1:2	1:3.894	04	complete matt glaze
A 7...	0.7 CaO 0.2 K_2O 0.1 MgO	0.20 Al_2O_3 0.40 B_2O_3	2.80	1:2	1:5.000	07—08	faultless matt glaze

If one heats matt glazes above their maturing temperature, they become clear, perhaps because, through the longer and more intensive action, they take silicic acid out of the body and thereby become more acid.[10]

The maturing temperatures, found, are not in contradiction to the facts found by Orton, although he, for the same temperatures, gave other basicities as correct and necessary for matt glazes. In the matt glazes upon which his curve is founded, only the general practical raw materials for raw glazes are used. To these B_2O_3 does not properly belong. By the introduction of unusual materials, the individual values were naturally changed, this being especially pronounced by the employment of boric acid, which yields a very easily fusible glaze. The opposite

[10] Trans. A. C. S., Vol. X, pp. 547-582.

phenomena would result from the molecular replacement of alumina by rare earths of higher molecular weight.

The essential fact in the above series of trials is that the Al_2O_3 in matt glazes may be replaced by equivalent amounts of B_2O_3, without the character of the glaze suffering any change aside from the reduction of melting point which must naturally occur.

This is only explainable by the assumption that Al_2O_3 and B_2O_3 act in like manner and that the opinion, originating with Seger and still generally prevailing, "that the boric acid may, in equivalent amounts, replace the silicic acid in glazes without changing the essential character of the glaze," proves incorrect.

The acceptance of B_2O_3 as acid in the investigated glazes, gives oxygen ratio of base to acid as high as 1 : 5. This is in absolute contradiction with the results of investigations of matt glazes, while if the B_2O_3 is added to the bases with the sesquioxides, it agrees very well with the results obtained. Based upon this fact, it seems practical to the author to insert the B_2O_3 in matt glazes, not in the column with the silicic acid but in the column of the sesquioxides.

B. The Influence of Al_2O_3 and B_2O_3 upon the Cobalt-Blue Glazes.

It is known that aluminum oxide changes the color of cobalt-blue glazes. Upon the basis of this fact the following investigation was undertaken, as to the extent of this change on replacing a part of Co_2O_3 with equivalent amounts of Al_2O_3, and also whether B_2O_3, in part or entirely, may be introduced in the place of Al_2O_3. This investigation starts with the glaze:

$$\text{B 1} \quad \left.\begin{matrix} 0.70\ Na_2O \\ 0.30\ PbO \end{matrix}\right\} \quad 0.088\ Co_2O_3 \qquad 3.00\ SiO_2$$

This was fritted and finely pulverized and had a violet-blue color.

If one-half of the cobalt oxide in this glaze is replaced by aluminum oxide it gives the following:

$$\text{B 2} \quad \left.\begin{matrix} 0.7\ Na_2O \\ 0.3\ PbO \end{matrix}\right\} \quad \left.\begin{matrix} 0.044\ Co_2O_3 \\ 0.044\ Al_2O_3 \end{matrix}\right\} \quad 3.00\ SiO_2$$

The color of the above corresponds with B 1 although distinctly darker. If in B 2 one half the Al_2O_3 is replaced by B_2O_3, the following glaze formula results:

$$\text{B 3} \quad \left.\begin{matrix} 0.7\ Na_2O \\ 0.3\ PbO \end{matrix}\right\} \quad \left.\begin{matrix} 0.044\ Co_2O_3 \\ 0.022\ Al_2O_3 \\ 0.022\ B_2O_3 \end{matrix}\right\} \quad 3.00\ SiO_2$$

This shows the same color and strength of shade as B 2, although the color is a trifle darker.

$$\text{B 4} \quad \left.\begin{matrix} 0.7\ Na_2O \\ 0.3\ PbO \end{matrix}\right\} \quad \left.\begin{matrix} 0.044\ Co_2O_3 \\ 0.044\ B_2O_3 \end{matrix}\right\} \quad 3.00\ SiO_2$$

In this glaze, one-half of the cobalt oxide in the original glaze, B 1, is replaced by boron trioxide. The glaze is scarcely noticeably darker than B 3, and possesses the same tint as B 2 and B 3. The differences between B 2, B 3 and B 4 are extremely small and only discernable to the trained eye, while the difference between the strengths of color in these glazes is easily noted in comparison with the original glaze, B 1. Through the above investigation, the industrially important fact is established that the color of cobalt-blue glazes become pronouncedly darker if the half of the Co_2O_3 is replaced by Al_2O_3. B_2O_3 brings out the same phenomena as the Al_2O_3, but in even slightly more pronounced degree.

The color action of these two oxides upon cobalt-blue glazes is the same in principle, and only differs in degree in that B_2O_3 acts more intensively than Al_2O_3.

Mr. Heinecke, artist to the Bunzlau Fachschule, kindly determined the color differences and verified them, and I would here express to him my thanks.

C. Influence of Al_2O_3 and B_2O_3 upon Turquoise-Blue Glazes.

Dr. W. Pukall has determined, by an earlier unpublished investigation, which he carried on from an entirely different standpoint, that aluminum oxide and boron trioxide change the turquoise-blue color of copper glazes to a dirty greenish-blue tint.

The following investigation, based on this information from Dr. Pukall, to whom I here express my thanks, will deal with the question of the extent to which Al_2O_3 and B_2O_3 exert a like or an unlike influence upon the color of the copper-blue.

The original glaze is:

C 1	0.64 Na_2O 0.27 PbO 0.09 CuO		3.00 SiO_2

This has a beautiful lively turquoise-blue color, but when converted into the glaze C 2

C 2	0.64 Na_2O 0.27 PbO 0.09 CuO	0.2 Al_2O_3	3.00 SiO_2

the color appears considerably weaker, and possesses a slight trace of green. This color change was more pronounced and distinct in Glaze C 3:

C 3	0.64 Na_2O 0.27 PbO 0.09 CuO	0.4 Al_2O_3	3.00 SiO_2

The same color tone was displayed by

C 4	0.64 Na_2O 0.27 PbO 0.09 CuO	0.1 Al_2O_3 0.1 B_2O_3	3.00 SiO_2

The glaze C 5 appears yet more pronouncedly greenish:

C 5	0.64 Na_2O 0.27 PbO 0.09 CuO	0.2 B_2O_3	3.00 SiO_2

If ZnO replaces PbO in the original glaze, giving glaze C 6,

C 6	0.64 Na_2O 0.27 ZnO 0.09 CuO	}	3.00 SiO_2

nearly the same color influence results from the introduction of B_2O_3 and Al_2O_3 as before.

It appears therefore that Al_2O_3 and B_2O_3 change the turquoise-blue color of copper glazes to a dirty greenish-blue in the same manner, and that the intensity of their action differs in that the B_2O_3 acts about twice as powerfully as Al_2O_3. It indicates the same phenomena as by the action of Al_2O_3 and B_2O_3 upon the cobalt-blue glazes, when the color change caused by B_2O_3 was also more intensive than that produced by Al_2O_3.

D. Comparison of the Influence of Al_2O_3 and B_2O_3 upon Green and Red Under-Glaze Colors.

K. J. Brick, in an article "Glaze Composition and its Influence upon Green and Red Under-Glaze Colors,"[11] discusses the different elements and their influence upon these colors. He first found that the following glazes brought out the above mentioned under-glaze colors in exceedingly good quality.

D 1	0.40 PbO 0.45 CaO 0.15 K_2O	}	0.25 Al_2O_3	}	2.80 SiO_2
D 2	0.40 PbO 0.40 CaO 0.15 K_2O 0.05 Na_2O	}	0.25 Al_2O_3		2.80 SiO_2

If in D 1 you replace 0.05 CaO, or in D 2 you replace 0.05 Na_2O by 0.05 BaO, you obtain the composition

D 3	0.40 PbO 0.40 CaO 0.15 K_2O 0.05 BaO	}	0.25 Al_2O_3	2.80 SiO_2

[11] Bruhn's Fachblatt, 1909, Nos. 42 and 43.

which has a very unfavorable influence upon green and red under-glaze colors. This injurious influence of barium is intensified through the action of boric acid, while in D1 and D 2 the introduction of B_2O_3 in as great amount as 0.2 molecule was not injurious.

However, if one increases the boric acid content in these glazes up to 0.3 molecule, the under glaze colors will likewise be destroyed.

Too great a content of alumina injures the colors also, in the absence of barium, especially when at the same time the boric acid content exceeds a certain limit. For example, glaze

$$\text{D 4} \quad \left.\begin{matrix} 0.40\ PbO \\ 0.45\ CaO \\ 0.15\ K_2O \end{matrix}\right\} \quad 2.94\ SiO_2 \qquad 0.32\ Al_2O_3$$

which is especially adapted for the favorable development of green and red under-glaze colors, becomes by the introduction of 0.2 B_2O_3 as indicated by the formula

$$\text{D 5} \quad \left.\begin{matrix} 0.40\ PbO \\ 0.45\ CaO \\ 0.15\ K_2O \end{matrix}\right\} \quad \left.\begin{matrix} 0.327\ Al_2O_3 \\ 0.200\ B_2O_3 \end{matrix}\right\} \quad 2.954\ SiO_2$$

worthless for this purpose.

Brick draws from this the following conclusion:

"The alumina appears to approach the barium in the above mentioned characteristic because the strong color-destroying peculiarity of the glazes with high kaolin content, like the barium glazes, also seems to depend upon the amount of boric acid contained.

However, he does not consider the fact that this small barium content (0.05 molecule in the glaze) opposes under glaze color development in the absence of B_2O_3, while on the other hand D 4, with an aluminum oxide content of 0.32 molecule, strongly favors the development of green and red colors. This property, moreover, is only lost by the introduction of 0.2 molecule of B_2O_3.

The action of BaO and Al_2O_3 is essentially different. BaO alone hinders under-glaze color development in every

case, even when its amount is very small (0.05 molecule) and in the absence of B_2O_3. Al_2O_3 on the contrary injures the green and red colors only when its amount is very large (see farther on) and when at the same time enough B_2O_3 is present, so that the sum of the sesquioxides reaches or exceeds a certain amount. Therefore the color-destroying properties of BaO and Al_2O_3 are not comparable.

The actions of Al_2O_3 and B_2O_3 are far more parallel. Each of the two oxides injures the color development under the glaze, not of itself, but only when their sum exceeds a certain amount. Thus a glaze developed from D 1 as follows:

D 6	0.40 PbO 0.45 CaO 0.15 K_2O	0.25 Al_2O_3 0.20 B_2O_3	2.80 SiO_2

with a total sesquioxide content of 0.45 molecule (0.25 Al_2O_3+0.20 B_2O_3) produces good red and green under the glaze, while the glaze D 7,

D 7	0.45 PbO 0.35 CaO 0.15 K_2O 0.05 Na_2O	0.22 Al_2O_3 0.30 B_2O_3	2.42 SiO_2

with the sum of the sesquioxides amounting to 0.52 molecules, destroys the above underglaze colors. Likewise D 4 with a content of 0.32 molecule Al_2O_3 develops red and green colors well, even when the alumina content is slightly increased and a little boric acid added, while D 5, giving a sum of sesquioxides of 0.527 molecule (.327 Al_2O_3+.200 B_2O_3) destroys the colors.

From this it appears that the unfavorable influence upon the colors mentioned begins with the increase in the amounts of Al_2O_3 and B_2O_3, and the maximum is reached so soon as their sum reaches or exceeds 0.52 molecule. This action may occur when one of these two oxides alone reaches the amount of 0.52 molecule. Unfortunately Brick gives no example of this, but says, confirming this supposition, "it appears that a glaze which is favorable to the develop-

ment of underglaze green and red colors may, by the increase of the additions of kaolin, destroy red and green colors in an exactly similar burn."

Concerning the similar action of Al_2O_3 and B_2O_3 upon red and green underglaze colors, I expect to complete the investigation of Bricks' series of tests, with similar bases, for example, (0.40 PbO, 0.45 CaO, 0.15 K_2O). I will slowly increase the Al_2O_3 content and then gradually replace the same by B_2O_3, in order to sharply compare the working of these two sesquioxides.

E. Test of Boro-silicate Fusions as to their Acidity or Basicity by means of Lead-Chromate as Indicator.

Willard L. Bruner[12] states that lead chromate is adaptable as an indicator of acidity or basicity of fusions, by employing a quantity equal to 20 to 30% of the melt. It appears as coral-red in basic fusions, and as a yellow color in acid fusions. To verify these colors I made the following fusions at approximately 1000°C:

E 1 PbO—2.0 SiO_2 (Acid to Base = 2:1)

The color of this fusion was orange yellow.

E 2 PbO—0.5 SiO_2 (Acid to Base = 1:2)

Color of the fusion, red.

After I had established the comparison of these colors I introduced boric acid into the following test fusion in order to verify the action:

E 3 $PbO \cdot B_2O_3 \cdot SiO_2$

If one considers the B_2O_3 as base, then the ratio of acid to base = 1:4. If B_2O_3 is considered as acid, the proportion is acid : base :: 4 : 1.

The color of the fusion was intense green.

E 4 $PbO \cdot B_2O_3 \cdot SiO_2$

By accepting B_2O_3 as acid or base the ratio of acid to base is 5:1 or 1:2 respectively.

[12] Trans. Amer. Cer. Soc., Vol. XI, p. 528.

The color of the fusion was intense green like E 3. Additional fusions containing boracic acid appeared the same.

The result of these tests is that lead chromate refuses to act as indicator in fusions containing boric acid because the boric acid appears to dissolve the lead chromate and to separate out green chromic-oxide. Therefore, nothing can be said concerning the basicity or acidity of borosilicate fusions.

F. Production of Crystallized Mutually Isomorphous Silicates of Al_2O_3, V_2O_3, Mn_2O_3, Fe_2O_3, Co_2O_3 and B_2O_3.[13]

In mineralogy, zeolites are defined as hydrated, generally well crystallized silicates of aluminum and some other oxide, generally calcium and sodium. They are nearly all colorless, transparent to translucent, and ordinarily glassy with pearly surfaces along cleavage lines. One characteristic property of the zeolite is its remarkable reaction capacity when compared with other silicates. Its sodium or calcium content can be replaced by other metals by merely washing with their salt solutions, as is shown by the following reaction:

$$\underset{\text{(Sodium Zeolite)}}{Na_2O \cdot Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O} + CaCl \rightleftharpoons \underset{\text{(Calcium Zeolite)}}{CaO \cdot Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O} + 2\ NaCl$$

This reaction is recurrent when an excess of NaCl is present; for example, the calcium zeolite above, produced from the sodium zeolite by means of calcium chloride, may, if an excess of the reaction product, NaCl, is present, again react and thus return to its original form.

These natural zeolites can also be produced artificially with the same crystalline form and the same capacity for exchanging their bases, when one fuses alumina minerals,

[13] See also "Artificial Zeolites," Spitzer and Singer, Report, German Chemical Society, 1910.

or silicate of alumina, or an aluminate with alkali silicate, or alkali or alkali-carbonate with addition of quartz. One must so regulate the proportions of the fusion that free alkali or alkali-carbonate is not contained in the molten mass. After fusion, leach the molten mass out with water. Thus one can produce artificial zeolites with changing silica content, although the most easily produced is by employment of 4 to 6 molecules of alkali silicate for each molecule of the desired zeolite. If the amount of the flux medium exceeds this limit, the zeolite becomes slimy and unfilterable. If one goes below the designed limit, hydrated zeolites will be obtained by the treatment with water, although a notable increase in their silica content occurs; the amount produced is reduced, and the property of exchanging its bases diminishes to zero.

The separation of the molten product by means of water becomes more difficult as the amount of flux-medium is reduced below the assigned limits, until finally the fusion obtained can absolutely not be broken up by water. The artificial zeolites obtained by this leaching process possess the general composition

$$Na_2O \cdot Al_2O_3 \cdot m\ SiO_2 \cdot n\ H_2O$$

and have a greater capacity for changing their alkalies than is possessed by the natual zeolites, although as already stated, this property diminishes with increased silica content.

The crystals obtained were foliated, with pearly luster, extraordinarily thin and of indefinite horizontal dimensions; they were, in general, very small and appeared to be only fragments of larger planes. Yet in many zeolite crystals produced, whose size exceeded 1 c. m. square, it was found that these were so thin that they could not be isolated and filtered without being broken. The conditions under which the large or the small crystals are obtained cannot yet be stated exactly. In many cases, large crystals were obtained the first time, while numerous repetitions of the same experiment resulted in producing only micro-

scopically small crystals; the reverse also occurred under apparently exactly the same research conditions.

Many zeolites tend to decompose from the action of water when subjected for a long time to such treatment in a warm condition. Other zeolites produced in exactly the same manner, and of exactly analogous composition, have been boiled in water for weeks without showing the slightest alteration. Certain zeolites cannot be heated at 100° C. for the purpose of drying after the leaching out with water, without baking strongly together. Apparently a decomposition occurs. Hence they must be washed with alcohol and, following that, with ether as a measure of precaution to drive out the moisture remaining.

I expect to publish all these special problems, not yet settled, in an exhaustive special investigation concerning "Artificial Zeolites."

The analyses of these substances do not correspond exactly with the theoretical formula. Differences occur up to more than ½%. These are to be accounted for, not only by unavoidable analytical errors, but also by the fact that it is not possible to free the substances from all adhering impurities, as is generally possible in organic chemistry.

The associated impurities are composed of the same materials and possess the same specific gravity as the substance sought, and therefore cannot be separated without additional treatment.

Up to the present time, silicate chemistry possesses no suitable criterion of the purity of its substances similar to that possessed by organic chemistry in its hair-line fixed fusion-point determinations for crystalline bodies, and its fixed boiling point determinations for fluid bodies. With these, decomposition prior to fusion or boiling occurs comparatively seldom, while with all zeolites, it results in a liberation of water.

For this reason, the analyses of the zeolites was undertaken immediately after they were leached out with

water, washed with alcohol and ether, dried at 100°C and bolted through a 2500 mesh (per square centimeter) sieve.

For the fusions, the following materials were employed: Na_2CO_3, K_2CO_3, B_2O_3, Al_2O_3, V_2O_3, Cr_2O_3, Mn_2O_3, Fe_2O_3, Co_2O_3 and SiO_2. Concerning the employment of kaolin, I would explain that it was rejected in order to work only with chemically pure materials.

All raw materials were obtained from the factory of C. A. F. Kahlbaum, in Berlin.

A fusion having the composition

F 1 $7\ Na_2O \cdot Al_2O_3 \cdot 10\ SiO_2$

compounded from

$$Na_2O \cdot Al_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

gave after leaching out with water, a crystalline zeolite, of which the average composition was determined. This composition corresponds nearly to the formula:

$$Na_2O \cdot Al_2O_3 \cdot 4\ SiO_2 \cdot 4\ H_2O$$

Following are the actual analysis of the body produced and the theoretical percentage composition of the body represented by the formula:

	Actual	Theoretical
Na_2O	13.16	13.00
Al_2O_3	21.12	21.38
SiO_2	50.09	50.54
H_2O	15.32	15.08
	99.69	100.00

The fusion

F 2 $6\ Na_2O \cdot Al_2O_3 \cdot 10\ SiO_2$

compounded from

$$Na_2O \cdot Al_2O_3 \cdot 5\ SiO_2 + 5\ Na_2SiO_3$$

gave, after leaching, a zeolite with very large crystals of which the following is the formula:

$$Na_2O \cdot Al_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O$$

	Actual	Theoretical
Na_2O	11.29	11.16
Al_2O_3	18.43	18.37
SiO_2	54.17	54.29
H_2O	16.32	16.18
	100.21	100.00

These two trials were made in connection with about forty others, based on the German Patent No. 186630 of J. D. Riedel, of Berlin, for the artificial duplication of naturally occurring potassium and sodium aluminum zeolites. This series of trials formed the starting point of further attempts to produce zeolites containing other bases than Al_2O_3. This oxide was gradually replaced in the fusion by V_2O_3, Mn_2O_3, Fe_2O_3, Co_2O_3 and finally by B_2O_3, (Cr_2O_3 gives no zeolite). As a result of the leaching of these fusions, crystallized, mutually isomorphous, colored zeolites were obtained. Part of these were far more difficult to handle than were the aluminum zeolites, but nevertheless were capable of isolation and analysis. They possessed not only the crystal form of the individual bodies, but also that important sign of the isomorph by which analogous composition may be indicated, viz., the ability to form mixed crystals. A series of similar crystallized zeolites were also obtained, in which more than one sesquioxide was contained in the R_2O_3, and this was shown in the changes in their colors.

These color changes produced by the employment of other color oxides, in connection with Al_2O_3, I compared with those zeolites which have B_2O_3 instead of Al_2O_3 as their cause, but otherwise of similar composition.

The following zeolites, chosen as examples from a series of trials of far in excess of 100 fusions, may prove the isomorphous nature of the different zeolites, including also the boron zeolites.

The fusion

F 3 $7\ Na_2O \cdot V_2O_3 \cdot 10\ SiO_2$

compounded from

$Na_2O \cdot V_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$

gave after the leaching with water an olive-green zeolite, of which the following formula was deduced:

$$Na_2O \cdot V_2O_3 \cdot 4\ SiO_2 \cdot 4\ H_2O$$

	Actual		Theoretical
Na_2O	11.49		11.80
V_2O_3	28.39	(Det. by Diff.)	28.58
SiO_2	46.12		45.91
H_2O	14.00		13.71
	100.00		100.00

The fusion

F 4 $7\ Na_2O—Cr_2O_3—10\ SiO_2$ $(Na_2O—Cr_2O_3—4\ SiO_2+6\ Na_2SiO_3)$

after the leaching with water, yielded no crystals, but a fine green slime without zeolitic characteristics. Ten other fusions, executed under every possible means of precaution for the production of chromium-zeolites, yielded likewise negative results. (The compositions and properties of the products obtained will be communicated later.) Chromium-oxide thus appears not to be able to go into chemical combination with silicic acid; for example, Dr. W. Pukall using an absolutely different method also failed in producing chromium silicate.

The fusion

F 5 $7\ Na_2O \cdot Mn_2O_3 \cdot 10\ SiO_2$

compounded from

$$Na_2O \cdot Mn_2O_3 \cdot 4\ SiO_2+6\ Na_2SiO_3$$

yielded by leaching with water a deep dark violet zeolite, of which the following formula was deduced:

$$Na_2O \cdot Mn_2O_3 \cdot 4\ SiO_2 \cdot 4\ H_2O$$

	Actual Composition	Theoretical Composition
Na_2O	11.32	11.64
Mn_2O_3	29.47	29.59
SiO_2	45.79	45.26
H_2O	13.48	13.51
	100.06	100.00

The fusion

F 6 $7\ Na_2O \cdot Fe_2O_3 \cdot 10\ SiO_2$

compounded from

$$Na_2O \cdot Fe_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded by leaching with water a bright brown zeolite, of which the following formula was deduced:

$$Na_2O \cdot Fe_2O_3 \cdot 4\ SiO_2 \cdot 4\ H_2O$$

	Actual Composition	Theoretical Composition
Na_2O	11.72	11.59
Al_2O_3	29.70	29.84
SiO_2	45.20	45.11
H_2O	13.28	13.46
	99.90	100.00

The fusion

F 7 $7\ Na_2O \cdot Co_2O_3 \cdot 10\ SiO_2$

compounded from

$$Na_2O \cdot Co_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded after leaching with water a blue-violet zeolite, of which the following formula was deduced:

$$Na_2O \cdot Co_2O_3 \cdot 4\ SiO_2 \cdot 4\ H_2O$$

	Actual Composition	Theorectial Composition
Na_2O	11.50	11.46
Co_2O_3	29.88	30.63
SiO_2	44.79	44.60
H_2O	13.52	13.31
	99.69	100.00

The fusion

F 8 $7\ Na_2O \cdot B_2O_3 \cdot 10\ SiO_2$

compounded from

$$Na_2O \cdot B_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded after leaching with water a colorless zeolite of

pearly luster, of which the following formula was deduced:

$$Na_2O \cdot B_2O_3 \cdot 4\ SiO_2 \cdot 4\ H_2O$$

	Actual Composition		Theoretical Composition
Na_2O	14.09		13.93
B_2O_3	15.17	(Det. by Diff.)	15.70
SiO_2	54.44		54.19
H_2O	16.30		16.18
	100.00		100.00

The fusion

F 9 $\quad 6\ Na_2O \cdot B_2O_3 \cdot 10\ SiO_2$

compounded from

$$Na_2O \cdot B_2O_3 \cdot 5\ SiO_2 + 5\ Na_2SiO_3$$

yielded, by leaching with water, a colorless zeolite, with pearly luster, of which the following formula was deduced:

$$Na_2O \cdot B_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O$$

	Actual Composition		Theoretical Composition
Na_2O	11.60		11.85
B_2O_3	13.86	(Det. by Diff.)	13.35
SiO_2	57.42		57.61
H_2O	17.12		17.19
	100.00		100.00

In the foregoing a selection of crystallized, mutually isomorphous zeolites has been described, in which the Al_2O_3 of the original zeolites was so replaced by different sesquioxides that the R_2O_3 consisted always of one oxide. The following description shows some mixed zeolites, in which the R_2O_3 consist of more than one sesquioxide, and following this are several mixed boron-zeolites.

The fusion

F 10 $\quad 7\ Na_2O \quad \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ Fe_2O_3 \end{matrix} \right\} \quad 10\ SiO_2$

compounded from

$$Na_2O \cdot 0.5\ Al_2O_3 \cdot 0.5\ Fe_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

gave, following the leaching out with water, a bright yellow zeolite, of which the following formula was deduced:

$$Na_2O \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ Fe_2O_3 \end{matrix} \right\} 4\ SiO_2\ \ 4\ H_2O$$

	Actual Composition	Theoretical Composition
Na_2O	12.09	12.25
Al_2O_3	10.01	10.08
Fe_2O_3	15.89	15.77
SiO_2	47.48	47.67
H_2O	14.30	14.23
	99.77	100.00

The fusion

$$\text{F 11}\quad 7\ Na_2O \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ Co_2O_3 \end{matrix} \right\} 10\ SiO_2$$

compounded from

$$Na_2O \cdot 0.5\ Al_2O_3 \cdot 0.5\ Co_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded, after the leaching with water, a blue-violet zeolite, the color of which was distinctly more intense than that of the cobalt zeolite F 7. The formula deduced from this zeolite was

$$Na_2O \left\{ \begin{matrix} 0.5\ Co_2O_3 \\ 0.5\ Al_2O_3 \end{matrix} \right\} 4\ SiO_2\ \ 4\ H_2O$$

	Actual Composition		Theoretical Composition	
Na_2O	12.02		12.18	
Al_2O_3, Co_2O_3	26.66	The sum was determined by difference	10.02 + 16.28	sum 26.30
SiO_2	47.12		47.38	
H_2O	14.20		14.14	
	100.00		100.00	

The fusion

$$\text{F 12}\quad 7\ Na_2O \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ B_2O_3 \end{matrix} \right\} 10\ SiO_2$$

compounded from

$$Na_2O \cdot 0.5\ Al_2O_3 \cdot 0.5\ B_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded, after leaching with water, a colorless zeolite, with

pearly luster, of which the following formula was deduced:

$$Na_2O \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ B_2O_3 \end{matrix} \right\} 4\ SiO_2\ \ 4\ H_2O$$

	Actual Composition		Theoretical Composition
Na_2O	13.17		13.44
Al_2O_3	11.18		11.06
B_2O_3	7.37	(Det. by Diff.)	7.58
SiO_2	52.66		52.31
H_2O	15.62		15.61
	100.00		100.00

The fusion

$$F\ 13\quad 7\ Na_2O \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ B_2O_3 \end{matrix} \right\} 11.\ SiO_2$$

compounded from

$$Na_2O \cdot 0.5\ Al_2O_3 \cdot 0.5\ B_2O_3 \cdot 5\ SiO_2 + 6\ Na_2SiO_3$$

yielded, after the leaching with water, a colorless zeolite, of which the following formula was deduced:

$$Na_2O \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ B_2O_3 \end{matrix} \right\} 5\ SiO_2\ \ 5\ H_2O$$

	Actual Composition		Theoretical Composition
Na_2O	11.25		11.49
Al_2O_3	9.32		9.46
B_2O_3	6.21	(Det. by Diff.)	6.48
SiO_2	56.62		55.89
H_2O	16.60		16.68
	100.00		100.00

The fusion

$$F\ 14\quad 7\ Na_2O \left\{ \begin{matrix} 0.5\ B_2O_3 \\ 0.5\ V_2O_3 \end{matrix} \right\} 11.\ SiO_2$$

compounded from

$$Na_2O \cdot 0.5\ B_2O_3 \cdot 0.5\ V_2O_3 \cdot 5\ SiO_2 + 6\ Na_2SiO_3$$

yields by the leaching with water, a light gray-green zeolite, which, however, on account of the extraordinary difficulty, I was not able to isolate.

The fusion

$$\text{F 15} \quad 7\ Na_2O \left\{ \begin{matrix} 0.5\ B_2O_3 \\ 0.5\ Mn_2O_3 \end{matrix} \right\} 10\ SiO_2$$

compounded from

$$Na_2O \cdot 0.5\ B_2O_3 \cdot 0.5\ Mn_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded, by leaching with water, a violet zeolite, of which the following formula was deduced:

$$Na_2O \left\{ \begin{matrix} 0.5\ B_2O_3 \\ 0.5\ Mn_2O_3 \end{matrix} \right\} 4\ SiO_2\ \ 4\ H_2O$$

	Actual Composition		Theoretical Composition
Na_2O	12.46		12.67
B_2O_3	6.72	(Det. by Diff.)	7.14
Mn_2O_3	16.29		16.15
SiO_2	49.68		49.32
H_2O	14.85		14.72
	100.00		100.00

The fusion

$$\text{F 16} \quad 7\ Na_2O \left\{ \begin{matrix} 0.5\ B_2O_3 \\ 0.5\ Fe_2O_3 \end{matrix} \right\} 10\ SiO_2$$

compounded from

$$Na_2O \cdot 0.5\ B_2O_3 \cdot 0.5\ Fe_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded, after leaching in water, a bright yellow zeolite, of which the following formula has been deduced:

$$Na_2O \left\{ \begin{matrix} 0.5\ B_2O_3 \\ 0.5\ Fe_2O_3 \end{matrix} \right\} 4\ SiO_2\ \ 4\ H_2O$$

	Actual Composition		Theoretical Composition
Na_2O	12.52		12.66
B_2O_3	6.82	(Det. by Diff.)	7.13
Fe_2O_3	16.35		16.23
SiO_2	49.52		49.24
H_2O	14.79		14.69
	100.00		100.00

The fusion

$$\text{F 17} \quad 7\ Na_2O \left\{ \begin{matrix} 0.5\ B_2O_3 \\ 0.5\ Co_2O_3 \end{matrix} \right\} 10\ SiO_2$$

compounded from

$$Na_2O \cdot 0.5\ B_2O_3 \cdot 0.5\ Co_2O_3 \cdot 4\ SiO_2 + 6\ Na_2SiO_3$$

yielded, after leaching with water, a deep darkblue zeolite, of which the following formula has been deduced:

$$Na_2O \left\{ \begin{matrix} 0.5\ B_2O_3 \\ 0.5\ Co_2O_3 \end{matrix} \right\} 4\ SiO_2\ 4\ H_2O$$

	Actual Composition		Theoretical Composition
Na_2O	12.30		12.58
B_2O_3	6.71	(Det. by Diff.)	7.09
Co_2O_3	17.08		16.89
SiO_2	49.74		48.93
H_2O	14.17		14.60
	100.00		100.00

All the above zeolites possess the characteristic property of the sodium-aluminum zeolites, namely, the ability to exchange their bases (RO) by means of washing with salt solutions of other mono- and bi-valent metals. From this it appears that the constitution of the different zeolites must be the same because, when the Al_2O_3 is replaced by equivalent amounts of other sesquioxides as B_2O_3, V_2O_3, Mn_2O_3, Fe_2O_3 and Co_2O_3, the characteristic properties, peculiar to this substance, are not changed absolutely, but only as to strength.

The comparative quantitative investigation of the extent of the property of exchange possessed by the individual substances is in process, and the results will be published later.

G. Analogous Color Action of Al_2O_3 and B_2O_3 in Artificial Crystalline Silicates, and in Glazes.

If the above described zeolites, whose compositions closely resemble the following bodies,

F 2 $\quad Na_2O \cdot Al_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O$

F 3 $\quad Na_2O \left\{ \begin{matrix} .5\ Al_2O_3 \\ .5\ B_2O_3 \end{matrix} \right\} 5\ SiO_2 \cdot 5\ H_2O$

F 9 $Na_2O \cdot B_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O$

be treated repeatedly with a water solution of copper sulphate, the sodium of the zeolite will gradually be completely replaced.

For example, on treating the zeolite F 2 with cupric sulphate:

F 18

$$Na_2O \cdot Al_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O + CuSO_4 = CuO \cdot Al_2O_3 \cdot 5\ SiO_2 5\ H_2O + Na_2SO_4$$

The analysis of this new zeolite gave on calculation the following fomula:

$$CuO \cdot Al_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O$$

	Actual Co position	Theoretical Composition
CuO	13.70	13.87
Al_2O_3	17.67	17.81
SiO_2	52.54	52.62
H_2O	15.83	15.70
	99.74	100.00

In a similar way, the zeolite F 13 yields a copper zeolite:

F 19 $CuO \left\{ \begin{matrix} 0.5\ Al_2O_3 \\ 0.5\ B_2O_3 \end{matrix} \right\} 5\ SiO_2\ 5\ H_2O$

	Actual Composition		Theoretical Composition
CuO	14.12		14.27
Al_2O_3	9.03		9.16
B_2O_3	5.98	(Det. by Diff.)	6.27
SiO_2	54.79		54.14
H_2O	16.08		16.16
	100.00		100.00

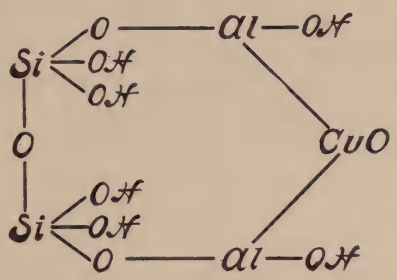
Similarly a third copper zeolite was made from F 9, with the following results:

F 20 $CuO \cdot B_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O$

	Actual Composition		Theoretical Composition
CuO	14.59		14.70
B_2O_3	12.60	(Det. by Diff.)	12.92
SiO_2	56.28		55.75
H_2O	16.53		16.63
	100.00		100.00

These three copper zeolites, F 18, F 19 and F 20, possess throughout a characteristic bright green color, apparently caused by their peculiar constitution.

One assumes in these that the chemical union of the RO bases is not to the silicic acid but to the sesquioxides, (R_2O_3), as indicated in the following structural formula:



In this aluminate-union, the copper oxide produces another color action than in the silicate-union. In the "Pukall" copper silicate, $CuO \cdot SiO_2 \cdot H_2O$, in which the copper oxide undoubtedly is directly united to the silicic acid, the color is pronouncedly bright blue. The fact is significant that in the three preceding copper-zeolites, the change of the bright-blue color of the sesquioxide-free copper zeolite to the bright green color of the copper zeolite containing sesquioxide, occurs in a similar manner. Whatever the true constitution of the zeolites may be, it is always to be supposed that the chemical union of the aluminum oxides and the boron-trioxide is alike, and that these substances, as is always the case with isomorphous compounds, can replace one another without producing other important changes than corresponds with their difference of molecular weight.

An analogous change of color from blue to green by introduction of Al_2O_3 or B_2O_3 respectively, (both sesquioxides in copper silicates), was described in the C series, where the turquoise-blue glazes:

$$C\ 1 \quad \left\{ \begin{matrix} 0.64\ Na_2O \\ 0.27\ PbO \\ 0.09\ CuO \end{matrix} \right\} \quad 3.00\ SiO_2$$

and

$$\text{C 6} \quad \left\{ \begin{matrix} 0.64\ Na_2O \\ 0.27\ ZnO \\ 0.09\ CuO \end{matrix} \right\} \quad 3.00\ SiO_2$$

were changed to dirty green by the introduction of Al_2O_3 or B_2O_3.

The chemical union of the color determining oxides, CuO, Al_2O_3 and B_2O_3 appear therefore to be, in copper-blue glazes, analogous to the zeolites. This is borne out also in the following example:

If one considers the above described zeolites, the compositions of which closely correspond to the following formula:

F 7 $\quad Na_2O \cdot Co_2O_3 \cdot 4\ SiO_2 \cdot 4\ H_2O$

$$\text{F 11} \quad Na_2O \quad \left\{ \begin{matrix} .5\ Al_2O_3 \\ .5\ Co_2O_3 \end{matrix} \right\} \quad 4.\ SiO_2 \quad 4\ H_2O$$

$$\text{F 17} \quad Na_2O \quad \left\{ \begin{matrix} .5\ B_2O_3 \\ .5\ Co_2O_3 \end{matrix} \right\} \quad 4.\ SiO_2 \quad 4\ H_2O$$

and determines their colors, one finds that F 7 having the greatest cobalt content is the lightest blue, that F 11 containing only half so much cobalt is stronger and brighter violet colored, while F 17 possesses a yet much deeper darker color. This is the same peculiar effect that the action of Al_2O_3 and B_2O_3 had upon the cobalt blue glaze,

$$\text{B 1} \quad \left\{ \begin{matrix} .7\ Na_2O \\ .3\ PbO \end{matrix} \right\} \quad .088\ Co_2O_3\ 3\ SiO_2$$

which I have described above. Also here, the color action of the boron-trioxides is similar to that of the aluminum oxides, and here also the boron is stronger. The color changes are decidedly more pronounced in the zeolites than in the cobalt-blue glazes, since one is working with more or less well-defined substances in the zeolites, while the glazes are solid solutions whose chemical interpretation is much more difficult. In any event, here again *a certain analogy between the composition of zeolites and glazes is established.* Upon this I base my manner of writing the cobalt-oxide in glazes as Co_2O_3, which is unusual, although in zeolites it is clearly established without

further research, upon the basis of the isomorphous form. *This analogy also justifies the conclusion that Al_2O_3 and B_2O_3 work in the same manner in glazes as in zeolites, and that therefore these two substances in the glaze formula are to be placed together in the sesquioxide column.*

Summary.

(A) The substitution of an equivalent amount of B_2O_3 for Al_2O_3 in matt glazes does not change the character of the glaze, but merely reduces the melting point. Al_2O_3 and B_2O_3 work so far in a similar manner, and as a result it seems settled that in the matt-glaze formula, B_2O_3 is not to be placed in the silica column but in the sesquioxide or R_2O_3 column.

(B) The color of cobalt-blue glazes is intensified through the replacement of half the Co_2O_3 by Al_2O_3. The same result is obtained by B_2O_3 as by Al_2O_3, but with even more intensity. The color influence of Al_2O_3 and B_2O_3 on cobalt glazes is the same in principle, but differs in that B_2O_3 works more powerfully than Al_2O_3.

(C) Both Al_2O_3 and B_2O_3 change the turquoise-blue color of copper glazes, in the same manner, to a dirty greenish blue. The intensity of their influence is different, in that B_2O_3 acts with about double the strength of Al_2O_3. The same phenomenon is noted here as in the operation of Al_2O_3 and B_2O_3 in cobalt glazes, in that the color change was more intense through employment of B_2O_3 than through Al_2O_3.

(D) An excess of Al_2O_3 and B_2O_3 acts disadvantageously upon red and green under glaze colors. This influence on colors is, however, not proportional with the amount of Al_2O_3 or B_2O_3 when present in small quantities, but only appears when their sum reaches or exceeds approximately 0.52 R_2O_3.

(E) The acidity or basicity of boro-silicates can not be proved by means of lead chromate as an indicator, be-

cause the latter is apparently decomposed by boric acid, so that the green chromic oxide separates out.

(F) If one melts aluminum minerals, aluminum silicates or aluminates with alkali silicate or with alkali carbonates with addition of quartz, and so regulates the proportions of the mixture that free alkali or alkali carbonate is not contained in the molten product, and leaches out with water, then one obtains aluminum zeolites in crystalline form. Similar isomorphous zeolites are obtained when the Al_2O_3 is molecularly replaced by B_2O_3, V_2O_3, Mn_2O_3, Fe_2O_3 and Co_2O_3. Attempts to produce Cr_2O_3 zeolites have failed. These boron, vanadium, manganese, iron and cobalt zeolites are mutually isomorphous, and possess the characteristic property of isomorphous bodies in forming mixed crystals. All possess the peculiarity of being able to exchange their bases, RO, by means of washing with salt solutions of mono- or bi-valent metals. By this it is shown that the constitution of all these different substances are analogous.

(G) The copper-aluminate and copper-borate zeolites possess the same bright green color, while the sesquioxide-free "Pukall" copper-silicate is bright blue.

In the first two cases I claim an aluminate and borate combination with copper-oxide has taken place, while in the latter case a silicate-combination exists. A parallel color change from blue to green through introduction of Al_2O_3 or B_2O_3 or both into copper silicate is illustrated in section C, when the turquoise blue glaze becomes dirty green. The chemical combination of CuO, Al_2O_3 and B_2O_3 appears to be the same in the copper blue glazes as in the zeolites. Through replacement of one-half the molecules of the Co_2O_3 in cobalt zeolite, by equivalent amounts of Al_2O_3 or B_2O_3, the color becomes distinctly more intense. B_2O_3 acts the same, in principle, as Al_2O_3, but more intensively. This is the same characteristic appearance as to the influence of Al_2O_3 and B_2O_3, as was noted with the two substances work in glazes in a similar manner, and

cobalt blue glaze. The color influence upon the zeolites is decidedly more pronounced in amount, though not different in kind.

Also, here a certain analogy between the constitution of zeolites and glazes is established. This analogy, in connection with all the above described corresponding properties of Al_2O_3 and B_2O_3, justifies the conclusion that these two substances work in glazes in a similar manner, and hence these two sesquioxides belong in the same column in the glaze formula.

The question whether Al_2O_3 and B_2O_3 in glasses and glazes work, in like manner, as bases or as acids, I leave open.

DISCUSSION.

Mr. Stull:—In his comparison of Al_2O_3 and B_2O_3 in matt glazes, Dr. Singer starts with a glaze having a total oxygen ratio of one to two. Is this not considered the best ratio for brilliant glazes? Then would not this glaze be matt from immaturity and in the strict sense not a true matt?

Starting with such a glaze and running a series by replacement of Al_2O_3 by B_2O_3 and reducing the temperature of firing, the glazes containing B_2O_3 are still matt from immaturity. Although I agree that B_2O_3 may function similar to Al_2O_3 in some cases, I dispute that its influence upon color is the same as that of Al_2O_3.

In a discussion of the possible colors obtainable from the different oxides, the question was raised as to whether it were possible to obtain a pink color from cobalt since we have pink cobalt salts. In searching for clues in an endeavor to produce a cobalt pink color, we find in blowpipe analysis that magnesia and magnesia minerals, when powdered and treated with a solution of cobalt nitrate and heated, will produce a pink color. Alumina and alumina minerals, when similarly treated, produce blue.

Accordingly two glazes were made free from alumina. One was made up of alkalies, magnesia and silica and soft-

ened with B_2O_3. The other glaze contained no B_2O_3, but was softened by replacing part of the MgO by PbO. The cobalt was precipitated from the nitrate and added to the glazes in hydroxide form.

Wall tile were dipped in these glazes and fired to cone 02. The glaze containing lead and no boric oxide was a deep blue—a little on the slate blue order—while the glaze containing boric oxide and no lead was a deep pink, or rather a lavender in color. Although the glazes were not perfectly fused they were highly vitrified and glossed. It is probable that if they had been well fused, enough alumina might have been taken up from the body to develop the blue color.

This is evidence that cobalt in the presence of lead will produce a blue color. In all of Dr. Singer's glazes in the cobalt series, lead is present, hence the blue color would be developed irrespective of the presence of boric oxide.

Mr. Purdy: Dr. Singer's paper may be divided into two parts. The first part is an empiric study of the relative influence and effect of B_2O_3 and Al_2O_3 in glazes and on colors. The second part is a scientific study of the displacement of Al_2O_3 by B_2O_3 in zeolites. Both of these parts are admirably handled. I wish to congratulate him upon the character of work he did on the zeolites.

We have in this paper an excellent contrast between empiric and scientific work. The former is the kind we are used to reading in our Transactions. That sort of work has a very decided value, but the evidence obtained is most largely circumstantial evidence, while the evidence obtained in scientific work, such as Dr. Singer has given us on zeolites, is positive evidence. I wish to discuss at this time only the first part of his paper, i. e., the empiric study with glazes and colors.

The work done with glazes and colors does not warrant positive statements regarding the chemical nature or behavior of B_2O_3. In fact, all of this is admitted by Dr.

Singer. His trials were glazes so compounded as to show the comparative influence of alumina and boracic acid. He also made color studies. The evidence he obtained is only indicative of similarity in action of Al_2O_3 and B_2O_3, but can give no positive conclusions as to the chemical role of B_2O_3 as compared with Al_2O_3.

Alumina will overcome crazing, while the preponderance of evidence is that B_2O_3 is quite neutral in this respect. Under some conditions, B_2O_3 will overcome crazing and in others it will provoke crazing. It depends upon the peculiar proportion of ingredients in the mix which results in the formation of certain compounds. I do not understand the situation because I have not had opportunity to learn what these compounds are, and probably would not realize the significance of such information even if I had it. All that I am able to say now is that when B_2O_3 is present in large amounts, in one class of glazes we get crazing; while in another class we would have crazing counteracted.

Dr. Singer has made several conclusions, based upon the supposition that both alumina and B_2O_3 produce crazing, and, in fact, he quotes Fox and myself to that effect. The empirical data reported by Fox and myself indicated that alumina would overcome crazing, while boracic acid would provoke crazing. The claim made by us for similarity and behavior of B_2O_3 and Al_2O_3 in fritted glazes, was in reference to de-vitrification only. I think Dr. Singer's argument for the identical role of Al_2O_3 and B_2O_3 would have been stronger if he had not cited the work of Fox and myself.

Prof. Orton:—Dr. Singer in his article has referred to a certain curve published by myself on page 578, Volume X, Transactions American Ceramic Society, as to the oxygen ratio of matt glazes. The lettering on this curve alone might lead one to think, as Dr. Singer evidently does, that I intended to claim the curve as of general application to the whole group of matt glazes. The context of the printed

matter immediately preceding and immediately following the curve shows very clearly that this was not my intention. For instance, on page 577, it is stated "This data emphasizes the facts already brought out and enables us to say with confidence, that *for this ratio,* and others of similar nature and belonging to this class, the oxygen ratios and temperatures which will produce matt textures are mutually dependent. * * * * *" (The italics were in the original). And later "(1) That matt glazes of good texture and ornamental appearance may be produced at temperatures ranging from cone 2 to cone 11, and probably at a still lower and still higher temperature, within the following ranges of composition:" Following which are the RO elements to which this statement applies. And lastly the concluding paragraph of my paper says "It is hoped that further work on this line by others may serve to extend the range of compositions to which these principles are known to apply." * * * *

These quotations show that at the time of writing I had no idea of laying down a general rule of basicity for matt glazes, and in fact that I took pains to guard myself against the very interpretation which Dr. Singer has applied to my work. Even if I had had such a notion, evidence is not lacking to overthrow it.

I wish to place on record my great appreciation of Dr. Singer's paper as a whole, and especially that portion dealing with the role played by B_2O_3 in zeolites, which seems to me a beautiful proof that in this class of bodies B_2O_3 does operate in the same way as Al_2O_3, whatever that may be. On the question of whether either is acting as an acid or a base, Dr. Seger very properly guards himself from taking sides.

NOTES ON THE MANUFACTURE OF ENAMEL BRICK WITH SOME INVESTIGATIONS ON ENAMEL BRICK SLIPS.

BY

R. T. STULL, Urbana, Ill.

Aside from the contribution by Barringer in Volume V of our Transactions, very little literature can be found of material assistance to the prospective manufacturer of enamel brick.

Although the fundamental principles of ceramics apply to the manufacture of enamel brick, they have not been clearly pointed out in this line of business; besides, there are problems peculiar to the trade which need more thorough investigation.

The majority of men in America, who are in charge of the manufacturing end, are of foreign birth. They have brought their experiences and recipes with them, and have gone through the painful experiences of applying them to our conditions. This has been largely responsible for the prevailing belief that "we must go abroad to get clays for our slips."* If all Europe should pass stringent laws prohibiting the exportation of her clays, it is not probable that the American white ware potters and enamel brick makers would go out of business, nor make any great sacrifices in the quality of their products.

Clays suitable for enamel brick bodies should possess low shrinkages, good bond, be free from warping and cracking, stand up well at cone 4 or higher, and burn to a light color comparatively free from iron spots.

The plastic fireclays are well suited to this purpose. It is quite essential, however, to reduce their shrinkages by the addition of flint clay or grog. The majority of body mixes vary from 60 to 80 plastic and 40 to 20 non-plastic

* Instead of "engobe" the writer prefers to use the word "slip" because it is the term universally understood by enamel brick makers.

parts. Some clays will carry a small percent of sand without material injury. One mixture which has been in use for several years is composed of 70 parts plastic clay, 20 parts grog, and 10 parts crushed sand stone.

METHODS OF MANUFACTURE.

In general, two different processes of manufacture are recognized, viz., one fire and two fire. In both one and two fire ware, the methods of applying the veneer are practically the same, the distinguishing feature being that, in the two fire process, the brick are first biscuited at a low temperature before the veneer is applied. Quite recently mechanical appliances have been introduced which promise to make some radical changes in the manufacture of enamel brick. For the present work, the methods of manufacture will be divided into two general groups, according to the methods of application of the veneer.

I. Hand Dipping Process.
   (a) Single Fire:
      1. Dipping Stiff Mud Brick,
      2. Dipping Leather Hard Brick,
      3. Dipping Bone Dry Brick.
   (b) Two Fire:
      1. Dipping Biscuited Brick.

II. Mechanical Veneering Process.
   (a) Single Fire:
      1. Veneering Stiff Mud Column and Wire Cutting.

A favorite method of making enamel brick in Europe is by dipping a stiff-mud wire-cut brick. The face of a first quality enamel brick must be as near perfect as it is possible to make it. Since the brick are not repressed, the die is watched with the greatest care, and frequently lined up to normal size in order to take up the wear.

It is important that the brick be cut straight. A method in vogue is to cut the column into blocks which

are dipped, and after the slip has hardened sufficiently, the blocks are "squared" on a hand cutting table. This is also an effective way of removing the excess slip on the sides.

Although this method has not been exploited to any extent in America, it has many advantages well worth investigating: 1. Repressing and consequent flaking of the slip due to oil on the surface are avoided. 2. There is a better bond between slip and body since the two shrink together in drying. 3. The necessity of storing the brick until they reach leather hard consistency is eliminated.

In the leather hard method, the brick are allowed to harden by partial drying until nearly all drying shrinkage has ceased before they are dipped. The brick may be formed on a soft-mud machine, or "slush" molded by hand in wooden molds, hardened down to a stiff-mud consistency and re-pressed, or, more commonly, made stiff mud on a plunger or auger machine, wire cut, and re-pressed. Owing to the variation in size and shape, the soft-mud machine method is to be recommended only where two grades of brick are to be made. By sorting the brick as they come from the repress, those which are true in form and size can be used for enameling and the remainder burned for builders.

The process of slush molding and repressing by hand is very similar to that for hand made fire brick, except that more care is taken in filling and dumping the molds and greater care exercised in repressing.

The advantages in repressing are that the brick can be "squared up," panelled and the firm's name stamped on the side. With the stiff-mud brick not subjected to the repress, the brick can be judiciously cored and the lettering stamped on the back side of the column by a roller.

A few plants are glazing bone dry brick. Although sold as enamel brick in some cases, they are in reality

nothing more than glazed brick, and should be classed as such.

To the writer's knowledge, there is not a plant at the present time successfully making a white enamel brick by dipping a bone dry body in slip and glaze. It is doubtful whether this method will ever be a success owing to difficulties encountered in cracking and flaking of the slip.

In the two fire process the brick may be made soft-mud repress, stiff-mud wire-cut, stiff-mud repress or dry-press process. The brick are first biscuited at heats ranging from cone 08 to cone 01, then dipped in slip and glaze and given the glost fire at cones 3 to 9. A few plants making dry pressed front brick from fire clays are enamelling their culls, which are too soft for the market or off in color but otherwise having true faces.

Methods of Dipping.

In some cases the brick are given one dip in the slip and one in the glaze, but in most cases the brick are given two dips in the slip and one in the glaze. A factory which has been brought to the writer's notice sprays on the first coat and dips the second one. Two slips of different composition are sometimes employed, the first dip being made in a slip comparatively high in ball clay and correspondingly low in China clay or kaolin. Over this a second coat is applied composed of materials giving a much whiter surface.

The thickness of the slip is an important factor. It is essential that it be applied thick enough in order to form a smooth coating and to hide the character of the body underneath. In the two fire process the brick may be porous enough to take on a sufficient coating in one dip, but for stiff-mud and leather-hard bodies, one dip is seldom sufficient, except in cases where a more or less opaque glaze is applied over. The proper thickness of the slip under ordinary conditions is from three-hundredths to five-hundredths of an inch. Where the slip is thin, the

differences in shrinkage and expansion of body and slip are balanced by the elasticity of the slip, thus preventing rupture. If the coating of slip is too thick, its shrinkage and expansive forces may cause cracking, crazing or flaking.

The glaze applied over the slip should be quite viscous so as to prevent excessive flow and beading along the edges, and to overcome the absorption of the glaze by the slip and the consequent vitrifying of the slip which would cause the dark color of the body to show through.

Defects Appearing After Dipping.

The principal defects which appear after dipping before the brick enter the kiln are:

1. Pinholes.
2. Flaking.
3. Cracking.

Pinholes.

Pinholes may occur from four causes: 1. Using a freshly made slip. 2. Pinholes or cavities in the surface of the brick. 3. Dust on the face to be dipped. 4. Bad dipping.

The writer has seen pinholes appear repeatedly by dipping brick in a freshly made slip. After ageing the slip for a short time, pinholes from this cause disappeared. A week's ageing of the slip is usually sufficient.

After dipping, the pinholes do not appear until the "water gloss" of the surface begins to disappear. Bubbles which appear on the surface break, leaving small cavities in the surface.

2. Air is entrapped in small cavities or pores in the dipped surface. As the water in the slip is absorbed by the brick, the air in these small cavities is forced out, passing up through the slip, thus causing pinholes.

3. In dipping a dusty surface, air is entrapped in films around the dust particles and in cavities between

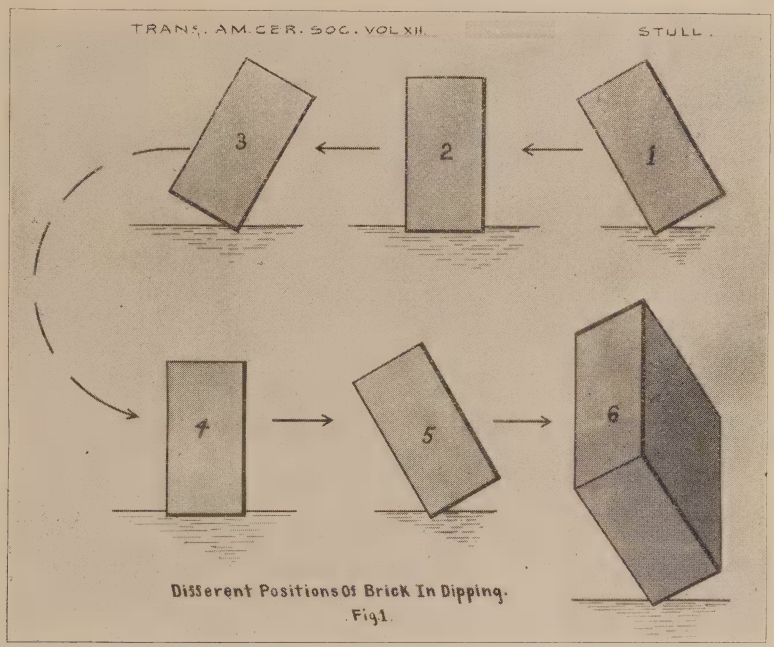
them. As the water in the slip slowly creeps over the surface of these particles, the air is released and rises to the surface.

In order to overcome pinholes caused by dust or minute cavities in the surface, brick makers resort to "scrubbing;" i. e., the surfaces to be enameled are brushed over with a stiff brush dipped in water, or more commonly, in a slip diluted with water. Other recipes which have been in use are: water, slip and glue; water, slip and molasses; water, fire clay and white slip.

4. Air may be entrapped by bad dipping. This occurs if a flat surface of the brick meets the surface of the slip when first immersed.

A good method of dipping is to hold the back of the brick in the palm of the hand with face to be dipped, down. By allowing one edge of the brick to first meet the surface of the slip as in position 1, the slip is washed across the face by a rocking motion through 2 to 3. Then by the reverse motion (without removing the brick from the slip), the brick is passed back through 4 to 5. The end of the brick farthest from the operator is then raised as in position 6, which allows the excess slip to run down the edge and leave at the corner as it is raised from the slip. The brick is then quickly inverted and slid onto a bench.

The dipping should be done by an easy swinging motion to and fro without a halt in the operation. The time required for a single dip is from three to six seconds, and a careful dipper can perform the operation alternately right and left handed, getting very little slip over the edges.



Flaking.

Flaking or shelling of the slip is due to lack of bond. It may occur soon after dipping or may not appear until the brick are subjected to the fire. Lack of bond may be caused by oil or dust on the surface, or by unequal shrinkage of slip and body. It is most frequently caused by too low shrinkage of the slip, but in some cases it is caused by too high shrinkage of the slip. In the latter case cracking and flaking will appear on the same surface.

Scrubbing the surface before dipping not only prevents pinholes, but also assists adhesion by removing dust and oil which may cause an otherwise good slip to flake.

Slips too low in plastic clay, or slips too high in kaolin or China clay which are short or weak in character will cause flaking. Where flaking is due to low shrinkage, the remedy is to increase the percent of plastic clay and de-

crease the non-plastic portion. Where cracking and flaking occur, reduce the percent of clay and substitute part ball clay for China clay or kaolin.

The tendencies of ball clay are to increase shrinkage, impart greater adhesive power and render the slip more yielding or ductile by which it adjusts itself better to the brick, thus preventing rupture.

Some English recipes for slips require plaster of paris to overcome flaking. It is necessary in such cases to exercise care in burning, besides, the cause of rough, blistered and scummed glazes can frequently be traced to plaster in the slip. The use of plaster to prevent flaking is unnecessary, since good reliable slips can be had without it.

Cracking.

Cracking may be caused by: 1. Excessive shrinkage of the slip. 2. Too thick a coating of slip. 3. Too fine grinding of slip. 4. In dipping leather hard, allowing the brick to become too dry before dipping. 5. Using clays which are weak or have low tensile strength.

Cracking may be overcome by substituting a clay of low shrinkage for one of higher; or increasing the non-plastic portion and decreasing the plastic part, such as increasing flint and feldspar or Cornwall stone, or replacing part raw clay with calcined clay.

Blunging the slip instead of grinding is to be recommended. The use of a small quantity of carbonate of soda or borax is found to be beneficial to overcome cracking. The proper amounts of these soluble materials to use is an important factor and varies in different slips, hence the amount should be determined experimentally. Slips high in clay require more than slips low in clay.

Mechanical Methods of Applying Slip.

The most universal method of applying slip and glaze is by hand dipping and removing the surplus on the sides by scraping with a knife or scratching with a fine wire brush. Quite recently a leading enamel brick plant has

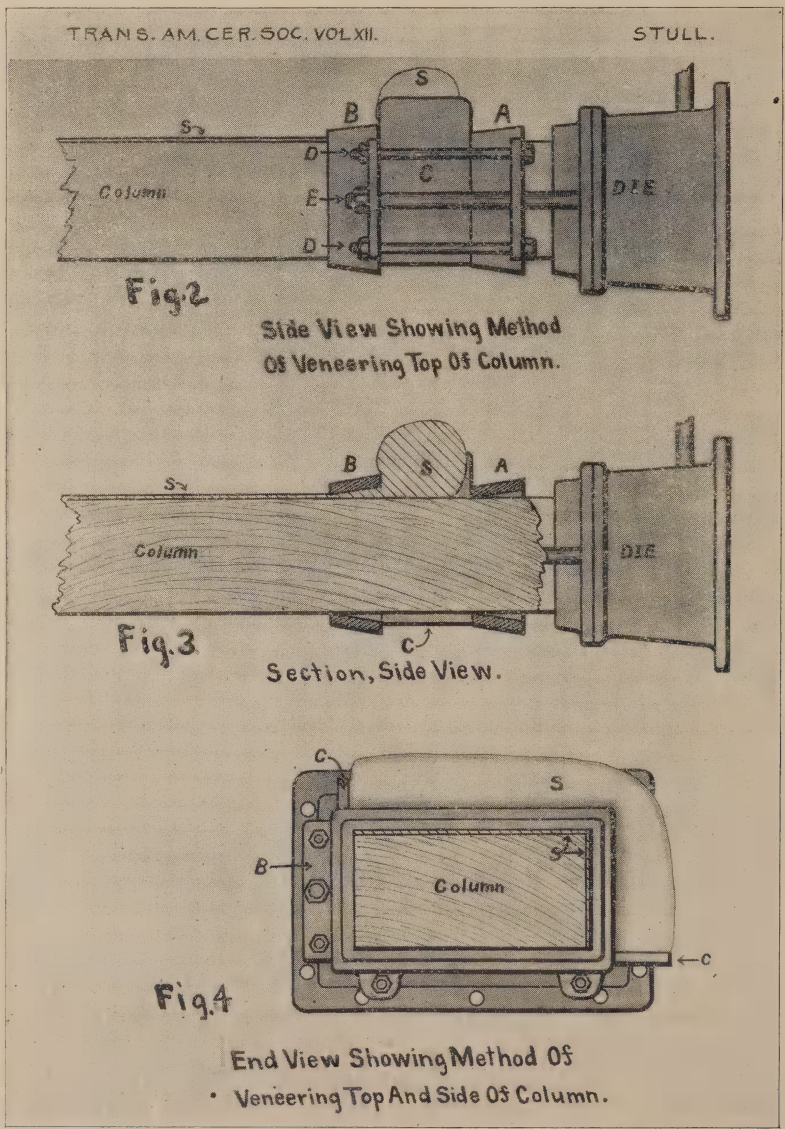
been experimenting with a dipping machine similar in construction to that used for dipping wall tile. The machine is made somewhat larger, with a few minor changes in its construction in order to make it more suitable for its new purpose.

The automatic veneering process is one which has a great future. The process consists in veneering a column of stiff mud clay after it issues from a die. For this purpose a veneering device is attached to the end of the die or placed in front of it for spreading the slip in a layer about one-sixteenth of an inch thick upon the faces to be veneered.

Although there are four American patents on devices for veneering a column of clay, but one of these seems to be successful for the manufacture of enameled brick, viz., the Ramsay patent, which has recently been brought to public notice by an infringement suit.

The veneering device consists of two rectangular frames A and B, called slickers, having two plates between as C, one at each side. These slickers are fastened together by two bolts at each side as DD. The apparatus is supported by the die and about one inch in front of it on two rods E, one at each side. Figs. 2 and 3 represent the apparatus rigged for making stretchers, in which case the top of the column is veneered. Fig. 4, a vertical section across the column, shows the arrangement for making quoins, in which case the top and one side of the column are veneered. The same principle is used for making bull nose and other shapes.

"A" is the surface preparing slicker having the same inside dimensions as the delivery end of the die. "B" is the slip slicker and is five sixty-fourths of an inch larger than the surface preparing slicker at all points where the slip is to be applied to the column. "S," the slip which is pugged to about the same consistency as clay used for pressing white ware, is placed upon the column between A and B. As the column moves forward the slip adheres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STULL.
S
B
A
S
D
C
Column
E
DIE
D
Fig.2
Side View Showing Method
Of Veneering Top Of Column.
B
S
A
S
Column
DIE
Fig.3
C
Section, Side View.
C
S
B
S
Column
C
Fig.4
End View Showing Method Of
Veneering Top And Side Of Column.

to it and rolls over and over, unwinding as it were, and is spread in a coating about one-sixteenth of an inch in thickness by the slip slicker "B."

The column is cut into brick on a hand cutting table of special design and dried on a hot floor. The bricks are loaded on trucks and the glaze applied by a large sprayer having the air and glaze under a pressure of forty to sixty pounds. The brick are then set and burned single fire.

Setting.

Of the three methods of burning, viz., open fire, burning in muffles and burning in saggers, the open fire method is most economical but requires considerable care and skill in setting. Some brick makers set the brick in piers, but the writer prefers setting in benches extending across the kiln. In two fire ware the brick may be set on the flat as described by Barringer,[1] but for single fire ware this method causes considerable loss in cracking owing to shrinkage. In order to overcome this difficulty, the stretchers on the outside of the benches are set on end and shapes set flat in the middle in piers, (Fig. 5).

In the single fire method the brick should go into the kiln bone dry. In the writer's experience, brick which were set wet frequently came out with a dry, rough surface as though the glaze were underfired. At other times the glaze would be blistered or badly scummed. These brick were called by the workmen "steamed brick." Repeated burning of these brick made no appreciable difference in their appearance.

It is probable that these brick being wet, took up sulphur dioxide from the kiln gases, which in turn oxidized to sulphuric acid. This naturally would combine with lime and zinc oxide present in the glaze, and since the kilns were burned oxidizing throughout, the sulphates would naturally remain as such.

[1] Trans. A. C. S., Vol. V, p. 273.

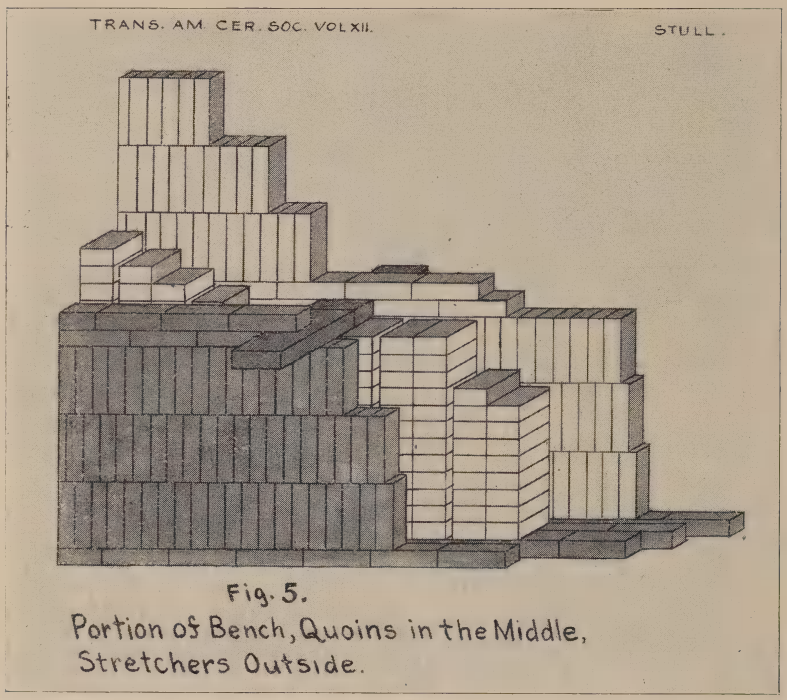


Fig. 5.
Portion of Bench, Quoins in the Middle, Stretchers Outside.

INVESTIGATIONS BY THE WRITER.

(Ceramic Laboratory, University of Illinois)

The following work comprises some investigations on enamel brick slips applied to leather hard, bone dry and biscuit bodies between the limits

25 to 75 parts clay materials,
75 to 25 parts non-plastic materials.

The ceramic materials employed were:

Georgia kaolin,
North Carolina kaolin,
Tennessee ball clay (No. 1),
Brandywine feldspar,
Ohio flint (8 hr. grind),
M. G. R. English China clay,

Pikes English ball clay (No. 20),
English Cornwall stone,
Carbonate of soda.

The objects of the work were to determine the range of good slips within the above named limits, to study the causes and remedies of defects, and to compare the slip making values of some of the English materials with those of a few American materials.

If a brick is to come from the kiln as a No. 1 article, it must first enter the kiln in No. 1 condition. The first step undertaken in the work was, to determine the ratios of plastic to non-plastic portions for slips which would fit the bodies perfectly in dipping, and which were to be used as bases for making the slips for the burning trials. For this purpose series 27, 28, 29 and 30 were constructed.

Carbonate of soda was kept constant at one percent in all slips throughout the work. All slips contained ten percent of ball clay, two different ball clays being employed for comparison.

The slips were weighed dry, blunged, passed through a 100 mesh screen, set at 1500 to 1520 B & L hydrometer, and placed in sealed jars and allowed to age for one week.

The body for the briquettes was composed of 70 parts plastic fire clay and 30 parts 16 mesh grog. The trials were made stiff mud on a small auger machine and wire cut.

The trials received two dips in the slip, the dipped surface first being scrubbed with two parts water and one part of the slip to be applied.

SERIES 27.
Ga. Kaolin—No. 1 Tenn. Ball.

No.	Kaolin	Tenn. No. 1 Ball.	Flint	Carbonate of Soda	On Leather Hard	On Bone Dry	On Biscuit	Basis for Series
185	15	10	75	1	Flaked Flaked	Flaked Flaked	Good	31 and 50
186	25	10	65	1		Cracked	Cracked	
187	35	10	55	1	Flaked Cracked	Cracked	Cracked Flaked	
188	45	10	45	1	Cracked	Cracked	Cracked	
189	55	10	35	1	Cracked	Cracked	Cracked	
190	65	10	25	1	Cracked	Cracked	Cracked	

In series 27 all slips flaked on leather hard trials, and flaked and cracked on bone dry. Slip No. 185, containing 15 Georgia kaolin and 75 flint, was good on biscuit. This slip was selected as the basis for Series 31 and 50. All other slips cracked and flaked.

SERIES 28.
N. C. Kaolin—No. 1 Tenn. Ball.

No.	N. C. Kaolin	Tenn No. 1 Ball	Flint	Carbonate of Soda	On Leather Hard	On Bone Dry	On Biscuit	Basis for Series
191	15	10	75	1	Flaked	Flaked	Good	32 and 51
192	25	10	65	1	Flaked	Flaked	Good	33 and 52
193	35	10	55	1	Flaked	Flaked	Good	34 and 53
194	45	10	45	1	Flaked	Flaked	Good	35 and 54
195	55	10	35	1	Flaked	Flaked	Good	36 and 55
196	65	10	25	1	Flaked	Flaked	Good	37 and 56

In Series 28 all slips fit perfectly on biscuit but flaked on bone dry and leather hard bodies.

SERIES 29.
N. C. Kaolin—English Ball.

No.	N. C. Kaolin	English Ball	Flint	Carbonate of Soda	On Leather Hard	On Bone Dry	On Biscuit	Basis for Series
197	15	10	75	1	Flaked	Good	Good	38 and 57
198	25	10	65	1	Flaked	Good	Good	39 and 58
199	35	10	55	1	Flaked	Good	Good	40 and 59
200	45	10	45	1	Flaked	Doubtful	Good	41 and 60
201	55	10	35	1	Good	Cracked	Good	42 and 61
202	65	10	25	1	Good	Cracked	Good	43 and 62

Series 29 is the same as Series 28 except that Pikes No. 20 English ball clay replaces Tennessee ball. In this series all slips work perfectly on biscuit, the three lowest in clay fit bone dry, the others cracked. The two highest in clay fit perfectly on leather hard.

SERIES 30.

English China—English Ball.

No.	English China	English Ball	Flint	Carbonate of Soda	On Leather Hard	On Bone Dry	On Biscuit	Basis for Series
203	15	10	75	1	Flaked	Good	Good	44 and 63
204	25	10	65	1	Good	Good	Good	45 and 64
205	35	10	55	1	Good	Cracked	Cracked	46 and 65
206	45	10	45	1	Good	Cracked	Cracked	47 and 66
207	55	10	35	1	Good	Cracked	Cracked	48 and 67
208	65	10	25	1	Good	Cracked	Cracked	49 and 68

Slips containing 15 to 25 China clay were good on biscuit and bone dry, the remainder cracked. The slip lowest in clay flaked on leather hard, the remainder were good.

Limits of Plastic and Non-Plastic for Dipping.

Selecting all slips which are good in the above four series, we find that for leather hard, perfect fitting slips in dipping lie within the range:

Clay .....35 to 75
Non-plastic .....65 to 25

For dipping bone dry:—

Clay .....25 to 45
Non-plastic .....75 to 55

For dipping biscuit:—

Clay .....25 to 75
Non-plastic .....75 to 25

Undoubtedly slips higher in clay would dip well on leather hard trials, but these were considered as impractical on account of crazing after burning, as will be shown later on.

Slips lower in clay would probably dip perfectly on biscuit, and here again we find crazing.

After determining the limits of plastic and non-plastic portions for perfect fitting slips in dipping, the next step in the work was to select each of the perfect working slips as a basis of a series in which the non-plastic portion was varied between flint and flux.

Series 31 and 50 are the only two containing Georgia kaolin which dipped well on biscuit. The other series are arranged in six groups, the flux in the first three being feldspar. The other three groups are a repetition of the first three, except that Cornwall stone was used as the flux in place of the feldspar.

Three different burns were made, viz., cones 4, 6 and 8. The variation in the kiln was such as to give cone 2 in the coolest part of the cone 4 burn, and cone 9 in the hottest part of the cone 8 burn. Trials were set on edge in tile saggers. Three trials of each slip were placed in each burn, two having glaze No. 5[1] applied over and the third slip left unglazed. Cones were also placed in each sagger.

A portion of each slip was cast $\frac{1}{4} \times \frac{1}{2} \times 1\frac{3}{4}$ inches in plaster molds. These cast trials were placed in the saggers with the dipped trials and used for determining the porosity of the slips. It was desirable to know what relation porosity had to the ability of slips to stand the freezing test. This part of the work is under way and not completed at the present writing.

[1] Trans. A. C. S., Vol. X, p. 218.

SERIES 31.

(On Biscuit)

No.	Constant	Flint	Spar	Cone 5	Cone 7	Cone 9
	Ga. Kaolin .....15 Tenn. Ball No. 1....10 Carbonate of Soda... 1					
209		60	15	Crazed	Crazed	Crazed
210		55	20	Crazed	Crazed	Crazed
211		50	25	Crazed	Crazed	Crazed
212		45	30	Crazed	Crazed	Crazed
213		40	35	Crazed	Crazed	Crazed
214		35	40	Crazed	Crazed	Crazed
215		30	40	Crazed	Crazed	Crazed
216		25	50	Crazed	Crazed	Crazed

All are good smooth slips but crazed. The glaze tends to decrease crazing of the slip. Crazing of slip increases with increase in temperature. Crazing decreases with replacement of flint by feldspar. No. 209 is a beautiful white, the whitest slip in the entire work.

Group I—Series 32 to 37.

SERIES 32.

(On Biscuit)

No.	Constant	Flint	Spar	Cone 6	Cone 7	Cone 9
	N. C. Kaolin.....15 Tenn. Ball No. 1....10 Carbonate of Soda... 1					
217		60	15	Crazed	Crazed	Crazed
218		55	20	Crazed	Crazed	Crazed
219		50	25	Crazed	Crazed	Crazed
220		45	30	Crazed	Crazed	Crazed
221		40	35	Crazed	Crazed	Crazed
222		35	40	Crazed	Crazed	Crazed
223		30	45	Crazed	Crazed	Crazed
224		25	50	Good	Slightly Crazed	Good

All are good slips except for crazing. Crazing decreases from 217 to 224 due to replacement of flint by

feldspar. Crazing of slips increase with increase in temperature. No. 224 is highly vitrified at Cone 9. This slip can be called good at Cone 6, but is too translucent at Cone 9. Slips are slightly cream colored.

SERIES 33.

(On Biscuit)

No.	Constant	Flint	Spar	Cone 6	Cone 7	Cone 9
	N. C. Kaolin.....25 Tenn. Ball No. 1....10 Carbonate of Soda... 1					
225		50	15	Good	Good	Good
226		45	20	Good	Good	Good
227		40	25	Good	Good	Good
228		35	30	Good	Good	Good
229		30	35	Good	Good	Good
230		25	40	Good	Good	Good
231		20	45	Good	Good	Good
232		15	50	Good	Good	Good

All slips work perfectly. The 10% increase in clay in this series above that in Series 32 has eliminated crazing entirely. Slips 229 to 232 are translucent at cone 8. Slips are a light cream in color.

SERIES 34.

(On Biscuit)

No.	Constant	Flint	Spar	Cone 6	Cone 7	Cone 9
	N. C. Kaolin.....35 Tenn. Ball No. 1....10 Carbonate of Soda... 1					
233		45	10	Good	Good	Good
234		40	15	Good	Good	Good
235		35	20	Good	Good	Good
236		30	25	Good	Good	Good
237		25	30	Good	Good	Good
238		20	35	Good	Good	Good
239		15	40	Good	Good	Good
240		10	45	Good	Good	Good

This series is similar to Series 33. No bad defects. Slips 237 to 240 are vitrified to a blue-white at Cone 9.

SERIES 35.

(On Biscuit)

No.	Constant	Flint	Spar	Cone 6	Cone 7	Cone 9
	N. C. Kaolin.....45 Tenn. Ball No. 1....10 Carbonate of Soda... 1					
241		40	5	Good	Good	Good
242		35	10	Good	Good	Good
243		30	15	Good	Good	Good
244		25	20	Good	Good	Good
245		20	25	Cracked	Cracked	Cracked
246		15	30	Cracked	Cracked	Cracked
247		10	35	Cracked	Cracked	Cracked

Slips are very good except a slight tendency to crack. Cracking increases with decrease in flint and increase in feldspar. Slips 245 to 247 are translucent at Cone 9. Nearly all the glazed trials are good. Glaze tends to overcome cracking of the slip.

SERIES 36.

(On Biscuit)

No.	Constant	Flint	Spar	Cone 6	Cone 7	Cone 9
	N. C. Kaolin.....55 Tenn. Ball No. 1....10 Carbonate of Soda... 1					
248		30	5	Good	Good	Good
249		25	10	Good	Good	Good
250		20	15	Good	Good	Good
251		15	20	Cracked	Cracked	Cracked
252		10	25	Cracked	Cracked	Cracked
253		5	30	Cracked	Cracked	Cracked

This series is similar to Series 35. The cracking, however, is a little more prominent.

SERIES 37.

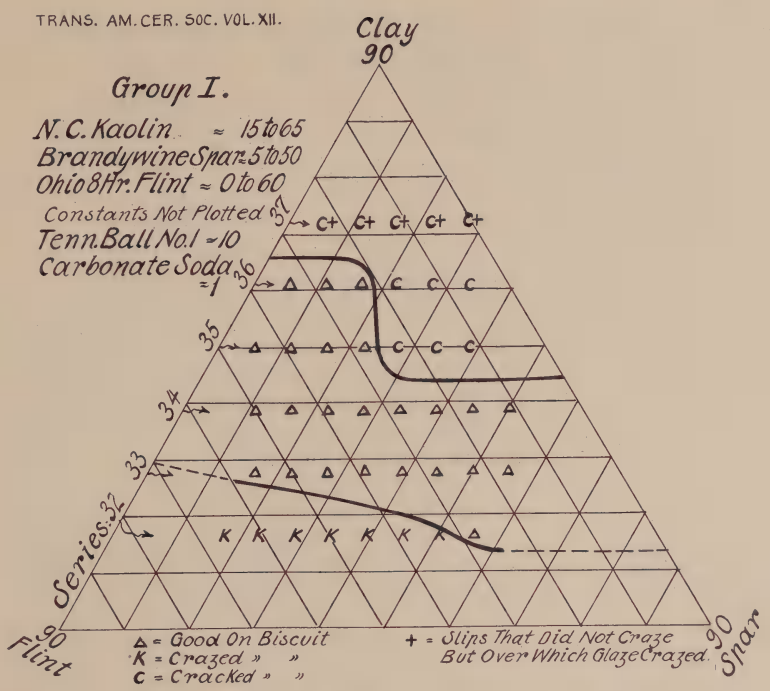
(On Biscuit)

Constant: N. C. Kaolin, 65; Tenn. Ball No. 1, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 3		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
254	20	5	Cracked	Crazed	Cracked	Good	Cracked	Cracked
255	15	10	Cracked	Crazed	Cracked	Good	Cracked	Good
256	10	15	Cracked	Crazed	Cracked	Crazed	Cracked	Good
257	5	20	Cracked	Crazed	Cracked	Crazed	Cracked	Good
258	0	25	Cracked	Crazed	Cracked	Crazed	Cracked	Good

All slips cracked. Glaze tends to prevent cracking of slip. Slips did not craze, but glazes crazed over slips in fine zig-zag lines. Increasing temperature of firing decreases crazing of the glaze.

The six different groups were plotted on tri-axial diagrams. In many cases the unglazed slips were defective and the same slips glazed were good. Only those slips were plotted as good which were sound both glazed and unglazed, and all such slips that were sound at one temperature, but may have been slightly defective at some other temperature, were plotted as good. Slips which were translucent (due to vitrification) but otherwise perfect were also plotted as good.



Conclusions on Group I.

Crazing: A high content of flint evidently causes crazing of the slip. Decreasing flint and increasing clay or feldspar, or both, decreases crazing. Increasing clay is more effective in overcoming crazing than increasing feldspar. With flint constant, decreasing clay and increasing feldspar, increases crazing. Crazing of the slip increases with increase in burning temperature.

A high content of clay does not cause the slip to craze, but causes the glaze applied over the slip to craze. Decreasing clay and increasing flint or feldspar, or both, in the slip decreases crazing of the glaze. Increasing the burning temperature decreases glaze crazing.

Cracking: Excessive clay in the slip causes cracking during burning. Decreasing clay and increasing flint or

feldspar, or both, decreases cracking. Increasing flint decreases cracking more effectively than increasing feldspar. With clay constant, decreasing flint and increasing feldspar increases cracking.

Good slips in this group on a biscuit body are found between the limits:

Georgia Kaolin	15 to 55	
Flint	10 to 50	
Feldspar	5 to 50	
Ball Clay	10	Constant
Carbonate of Soda	1	Constant

Group II. Series 38 to 43.

SERIES 38.

(On Biscuit)

Constant: N. C. Kaolin, 15; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 3		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
259	60	15	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed
260	55	20	Crazed	Crazed	Crazed	Crazed	Crazed	Good
261	50	25	Crazed	Crazed	Crazed	Good	Crazed	Good
262	45	30	Crazed	Crazed	Good	Good	Crazed	Good
263	40	35	Good	Good	Good	Good	Crazed	Good
264	35	40	Good	Good	Good	Good	Crazed	Good
265	30	45	Good	Good	Good	Good	Crazed	Good
266	25	50	Good	Good	Good	Good	Crazed	Good
267	20	55	Good	Good	Good	Good	Crazed	Good

Crazing of unglazed slips increases and crazing of glazed slips decreases with increase in temperature. Crazing decreases with increase in feldspar. Aside from crazing, slips fit perfectly. Slips 264 to 267 are translucent at Cone 6, due to vitrification. Slips 261 to 267 are translucent at Cone 9.

SERIES 38.

(On Bone Dry)

No.	Cone 3		Cone 5		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
259	Crazed Cracked	Crazed	Crazed Cracked	Crazed	Crazed Cracked	Good
260	Crazed Cracked	Crazed	Crazed Cracked	Good	Crazed Cracked	Good
261	Crazed Cracked	Crazed	Crazed Cracked	Good	Crazed Cracked	Good
262	Crazed Cracked	Good	Crazed Cracked	Good	Cracked	Good
263	Crazed	Good	Crazed Cracked	Good	Good ?	Good
264	Crazed	Good	Cracked	Good	Cracked	Good
265	Good	Good	Cracked	Good	Good ?	Good
266	Good	Good	Good	Good	Good ?	Good
267	Good	Good	Good	Good	Cracked	Good

Slips show a tendency to crack. Cracking does not seem to be influenced by variation in composition or heat treatment. Cracks extend down into the body about 1/32 to 1/16 of an inch.

SERIES 39.

(On Biscuit)

Constant: N. C. Kaolin, 25; English Ball, 10; Carbonate of Soda, 1.

No	Flint	Spar	Cone 4		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
268	50	15	Good	Good	Good	Good	Cracked	Good
269	45	20	Good	Good	Good	Good	Cracked	Good
270	40	25	Good	Good	Good	Good	Cracked	Cracked
271	35	30	Good	Good	Good	Good	Good	Good
272	30	35	Good	Good	Good	Good	Good	Good
273	25	40	Good	Good	Cracked	Cracked	Cracked	Cracked
274	20	45	Good	Good	Cracked	Good	Good	Good
275	15	50	Good	Good	Cracked	Good	Good	Good

Slips have a slight tendency to crack, which increases with increase in feldspar and temperature. Glaze over the slip tends to prevent cracking. (See Fig. 6). All slips are opaque at Cone 6. Slips 272 to 275 are vitrified and translucent at Cone 8.

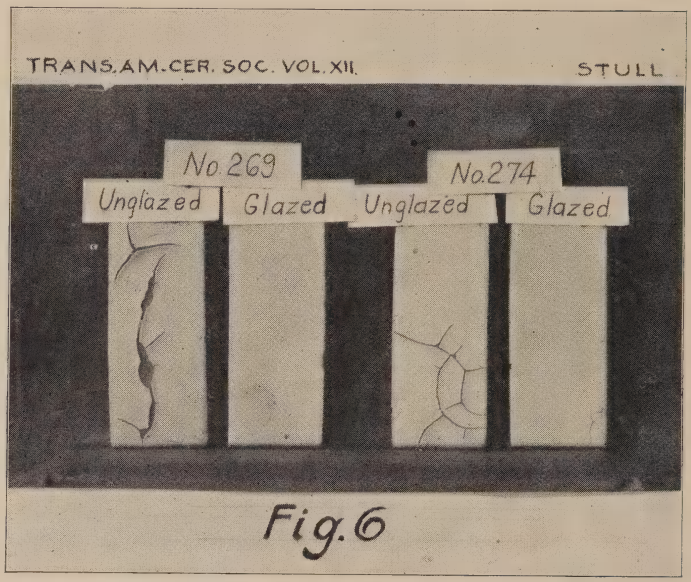


Fig. 6

ILLUSTRATIONS OF GLAZE PREVENTING SLIPS FROM CRACKING.

SERIES 39.

(On Bone Dry)

No.	Cone 4		Cone 6		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
268	Cracked	Good	Cracked	Cracked	Cracked	Cracked
269	Cracked	Good	Cracked	Good	Cracked	Good
270	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
271	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
272	Cracked	Cracked	Cracked	Good	Cracked	Cracked
273	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
274	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
275	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked

Cracking quite bad; worse than series 38.

SERIES 40.

(On Biscuit)

Constant: N. C. Kaolin, 35; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 4		Cone 6		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
276	45	10	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
277	40	15	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
278	35	20	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
279	30	25	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
280	25	30	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
281	20	35	Cracked	Cracked	Cracked	Good	Cracked	Cracked
282	15	40	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
283	10	45	Cracked	Good	Cracked	Good	Cracked	Good

Cracking of slips very bad. Cracking decreases with increase in feldspar. Glaze tends to prevent cracking of the slip. All slips are opaque at Cone 4. Slips 281 to 283 at Cone 6, and 279 to 283 at Cone 9 are vitrified.

SERIES 40.

(On Bone Dry)

No.	Cone 4	Cone 6	Cone 9
276	Cracked	Cracked	Cracked
277	Cracked	Cracked	Cracked
278	Cracked	Cracked	Cracked
279	Cracked	Cracked	Cracked
280	Cracked	Cracked	Cracked
281	Cracked	Cracked	Cracked
282	Cracked	Cracked	Cracked
283	Cracked	Cracked	Cracked

All slips both glazed and unglazed crack badly. Cracking extends through slips into the body.

SERIES 41.

(On Biscuit)

Constant: N. C. Kaolin, 45; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 5		Cone 7		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
284	35	10	Cracked	Good	Cracked	Good	Good	Cracked
285	30	15	Good	Good	Cracked	Good	Good	Good
286	25	20	Good	Good	Cracked	Cracked	Cracked	Cracked
387	20	25	Cracked	Good	Cracked	Good	Cracked	Good
288	15	30	Good	Good	Good	Cracked	Good	Good
289	10	35	Cracked	Cracked	Cracked	Good	Cracked	Cracked

Slips which cracked showed a tendency to curl up and flake. All slips are opaque at Cone 9.

SERIES 42.

(On Biscuit)

Constant: N. C. Kaolin, 55; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 5		Cone 7		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
290	30	5	Cracked	Good	Cracked	Good	Cracked	Good
291	25	10	Cracked	Good	Cracked	Cracked	Cracked	Cracked
292	20	15	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
293	15	20	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
294	10	25	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
295	5	30	Cracked	Good	Cracked	Good	Cracked	Good

This series acts very similarly to Series 41.

SERIES 42.

(On Leather Hard)

No	Cone 5	Cone 7	Cone 9
290	Good	Good	Good
291	Good	Good	Good
292	Good	Good	Good
293	Good	Good	Good
294	Good	Good	Good
295	Good	Good	Good

All slips are good both glazed and unglazed, except that the glaze flakes from the slip slightly. Slips, however, fit perfectly. All slips are opaque at Cone 9.

SERIES 43.

(On Biscuit)

Constant: N. C. Kaolin, 65; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 5		Cone 7		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
296	20	5	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
297	15	10	Cracked	Cracked	Cracked	Good	Cracked	Cracked
298	10	15	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
299	5	20	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
300	0	25	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked

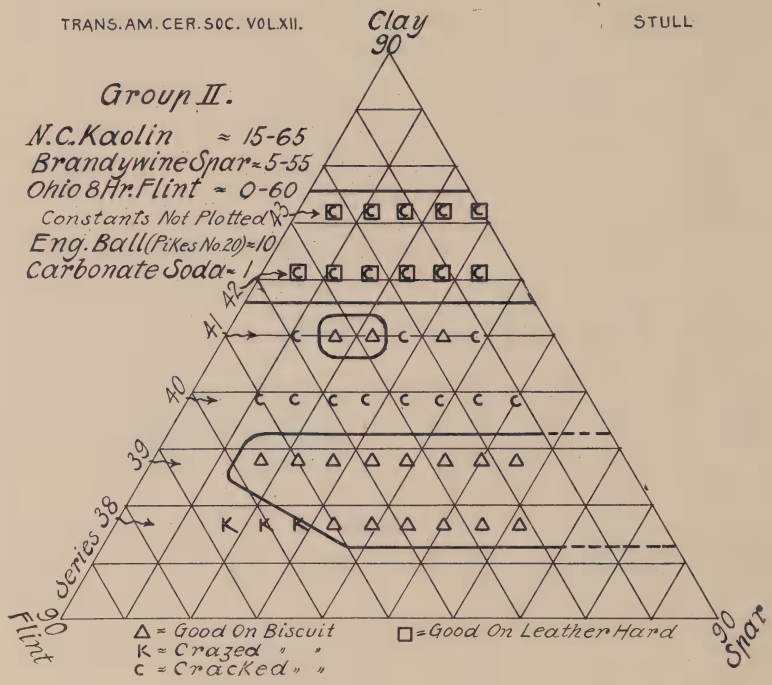
Cracking is very bad. Slips also flake some but not badly. All slips are opaque at Cone 9.

SERIES 43.

(On Leather Hard)

No.	Cone 5	Cone 7	Cone 8
296	Good	Good	Good
297	Good	Good	Good
298	Good	Good	Good
299	Good	Good	Good
300	Good	Good	Good

All slips work perfectly both glazed and unglazed. Glaze, however, flaked from slips; otherwise all trials were sound.



Conclusions on Group II.

The conclusions drawn with respect to crazing and cracking in Group I apply to Group II. There is a tendency of slips high in clay to flake as well as crack on biscuit body. Series 42 and 43, which are applied to leather hard body as well as biscuit, gave good results on the leather hard body, but cracked on biscuit.

In comparing the tri-axial diagram of Group II with that of Group I it is observed that the substitution of Pikes No. 20 English ball clay for Tennessee ball clay No. 1, has given a much smaller field of good slips on biscuit body; cracking has increased and crazing of slips decreased. Good slips are obtained which possess satisfactory working qualities on leather hard body. None of the slips were good on bone dry body.

The limits of composition for good slips on biscuit found in this group are:

North Carolina Kaolin	15 to 25	
Brandywine Feldspar	15 to 55	
Ohio Flint	15 to 50	
Pikes No. 20 Eng. Ball Clay	10	Constant
Carbonate of Soda	1	Constant

The limits for good slips on leather hard body are:

North Carolina Kaolin	55 to 65	
Brandywine Feldspar	5 to 30	
Ohio Flint	0 to 30	
Pikes No. 20 Eng. Ball Clay	10	Constant
Carbonate of Soda	1	Constant

Group III—Series 44 to 49.

SERIES 44.

(On Biscuit)

Constant: English China, 15; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 5		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
301	60	5	Cracked Crazed	Crazed	Cracked Crazed	Crazed	Cracked Crazed	Crazed
302	55	20	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed
303	50	25	Cracked Crazed	Crazed	Cracked Crazed	Crazed	Cracked Crazed	Crazed
304	45	30	Crazed Cracked	Crazed	Cracked Crazed	Good	Cracked Crazed	Crazed
305	40	35	Crazed	Crazed	Cracked	Good	Crazed	Good
306	35	40	Cracked Crazed	Crazed	Crazed Cracked	Crazed	Crazed Cracked	Crazed
307	30	45	Crazed	Crazed	Crazed	Crazed	Crazed	Good
308	25	50	Crazed	Crazed	Cracked	Good	Good	Good
309	20	55	Crazed	Crazed	Crazed	Good	Good	Good

All slips crazed. Glaze also crazed at low temperatures. Increase of temperature decreases crazing of the glaze. The glaze tends to prevent crazing of the slip. Very little difference is noticed in crazing of the slip due to difference in heat treatment. A decrease in crazing is noticeable with reduction of flint and increase in feldspar. Cracking is due to excessive fire shrinkage. Slips are all quite dense.

SERIES 44.

(On Bone Dry)

No.	Cone 5		Cone 6		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
301	Cracked Crazed	Cracked Crazed	Cracked Crazed	Cracked Crazed	Cracked Crazed	Cracked Crazed
302	Cracked Crazed	Cracked Crazed	Crazed	Crazed	Cracked Crazed	Cracked Crazed
303	Cracked Crazed	Cracked Crazed	Cracked Crazed	Crazed Cracked	Cracked Crazed	Cracked Crazed
304	Cracked Crazed	Cracked Crazed	Cracked Crazed	Crazed Cracked	Cracked Crazed	Cracked Crazed
305	Cracked Crazed	Cracked Crazed	Cracked Crazed	Crazed Cracked	Cracked Crazed	Cracked Crazed
306	Crazed Cracked	Cracked Crazed	Cracked Crazed	Crazed Cracked	Cracked Crazed	Cracked Crazed
307	Crazed Cracked	Cracked Crazed	Crazed	Crazed Cracked	Cracked Crazed	Cracked Crazed
308	Crazed Cracked	Cracked Crazed	Cracked Crazed	Crazed Cracked	Cracked	Cracked
309	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed

In general, slips crack badly. Cracking extends down into body. Crazing is the same as observed on biscuit. Nearly all slips are vitrified. Nos. 304 to 309 are glossed in the unglazed condition at Cone 8.

SERIES 45.

(On Biscuit)

Constant: English China, 25; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Spar	Cone 5		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
310	50	15	Crazed Cracked	Good	Good	Good	Good	Cracked
311	45	20	Crazed Cracked	Crazed	Cracked	Cracked	Cracked	Cracked
312	40	25	Crazed	Good	Good	Good	Good	Cracked
313	35	30	Good	Good	Good	Cracked	Good	Cracked
314	30	35	Cracked	Good	Crazed	Good	Cracked	Good
315	25	40	Cracked	Good	Crazed	Cracked	Cracked	Cracked
316	20	45	Cracked	Cracked	Good	Good	Cracked	Cracked
317	15	50	Good	Good	Good	Good	Cracked	Cracked

Crazing of slips decreases with decrease of flint and

increase of feldspar. Crazing also increases with increase in temperature. Slips are all opaque at Cone 4. No. 317 is translucent at Cone 6. Slips 313 to 317 are translucent at Cone 8.

SERIES 45.

(On Bone Dry)

No.	Cone 4		Cone 6		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
310	Cracked Crazed	Cracked	Cracked Crazed	Good	Good	Cracked
311	Cracked	Cracked	Cracked Crazed	Cracked	Cracked	Cracked
312	Cracked	Cracked	Cracked Crazed	Cracked	Cracked	Cracked
313	Good	Cracked	Cracked Crazed	Cracked	Cracked	Cracked
314	Cracked	Cracked	Cracked Crazed	Cracked	Cracked	Cracked
315	Cracked	Cracked	Cracked Crazed	Cracked	Cracked	Cracked
316	Good	Cracked	Cracked Crazed	Cracked	Cracked	Cracked
317	Cracked	Cracked	Cracked Crazed	Cracked	Cracked	Cracked

Slips behave in a similar manner to what they do on biscuit, except that they crack worse and have a slight tendency to flake.

SERIES 45.

(On Leather Hard)

No.	Cone 4	Cone 6	Cone 8
310	Flaked Crazed	Flaked	Flaked
311	Flaked Crazed	Flaked	Good
312	Flaked Crazed	Flaked	Flaked
313	Cracked	Cracked	Cracked
314	Flaked	Flaked	Flaked
315	Flaked	Flaked	Flaked
316	Good	Good	Good
317	Flaked	Flaked	Flaked

Both unglazed and glazed slips flake some. Slip 313, which cracked, was dipped quite thick.

SERIES 46.

(On Leather Hard)

No.	Constant	Flint	Spar	Cone 3	Cone 5	Cone 8
318	English China .....35 English Ball .....10 Carbonate of Soda... 1	45	10	Good	Good	Good
319		40	15	Good	Good	Flaked
320		35	20	Cracked	Good	Good
321		30	25	Flaked	Flaked	Flaked
322		25	30	Good	Good	Good
323		20	35	Flaked	Good	Flaked
324		15	40	Good	Good	Good
325		10	45	Flaked	Good	Good

Slips have a slight tendency to flake. Flaking not bad. Some very good slips appear. All are opaque at Cone 2. Slips 323 to 325 are vitrified at Cone 6. Slips 321 to 325 are vitrified at Cone 8.

SERIES 47.

(On Leather Hard)

No.	Constant	Flint	Spar	Cone 4	Cone 5	Cone 8
326	English China .....45 English Ball .....10 Carbonate of Soda... 1	40	5	Good	Good	Good
327		35	10	Good	Good	Flaked
328		30	15	Good	Good	Good
329		25	20	Cracked	Cracked	Flaked
330		20	25	Flaked	Flaked	Flaked
331		15	30	Flaked	Flaked	Flaked
332		10	35	Good	Flaked	Flaked

Slips flake more than Series 46. Flaking seems to increase with increase in feldspar and increase in temperature. All are opaque at Cone 4. Slips 330 to 332 are translucent at Cone 9.

SERIES 48.

(On Leather Hard)

No.	Constant	Flint	Spar	Cone 4	Cone 6	Cone 8
333	English China .....55 English Ball .....10 Carbonate of Soda... 1	30	5	Cracked	Good	Cracked
334		25	10	Good	Flaked	Flaked
335		20	15	Flaked	Flaked	Good
336		15	20	Flaked	Good	Good
337		10	25	Flaked	Flaked	Flaked
338		5	30	Flaked	Flaked	Good

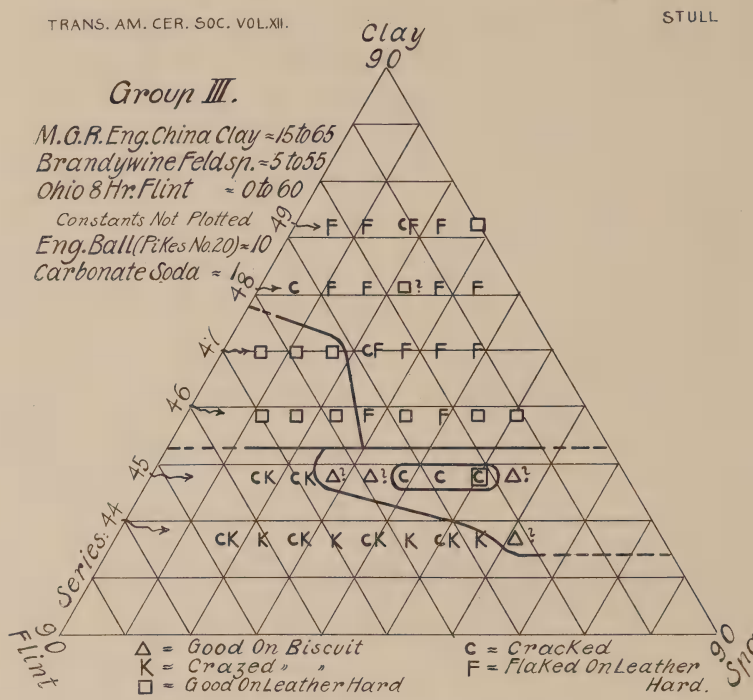
This series appears very similar to Series 47. All are opaque at Cone 8.

SERIES 49.

(On Leather Hard)

No.	Constant	Flint	Spar	Cone 4	Cone 6	Cone 9
339	English China .....35 English Ball .....10 Carbonate of Soda... 1	20	5	Good	Flaked	Flaked
340		15	10	Good	Flaked	Flaked
341		10	15	Cracked	Cracked	Flaked
342		5	20	Good	Flaked	Flaked
343		0	25	Good	Good	Good

Flaking in this series has increased over Series 48. All are opaque at Cone 9.



Conclusions on Group III.

Crazing and Cracking: The same conclusions on crazing found in Groups I and II also apply to Group III. Crazing of the slips has increased considerably over the two preceding groups. Since cracking is so erratic, no definite conclusions can be drawn.

Flaking: Flaking on leather hard trials during burning appears to be caused by too high clay content. Decreasing clay and increasing flint or feldspar, or both, decreases flaking during burning. Increasing flint overcomes flaking more effectively than increasing feldspar. With clay constant, decrease of flint and increase of feldspar increases flaking. The trials also show that flaking increases with increase in burning temperature.

The slips plotted as good on biscuit are in reality

doubtful. This field has dwindled considerably when compared to Groups I and II. A field of good slips on leather hard trials appears in an entirely different locality on the tri-axial diagram than that obtained in Group II.

The comparison of Groups II and III shows that the substitution of M. G. R. English China clay for North Carolina kaolin has increased crazing and cracking on biscuit trials, and increased flaking and cracking on leather hard trials. Examination of the trials shows that the English china clay produces slips which approach whiteness more closely and which vitrify at a lower temperature.

The limits of composition for good slips on biscuit body are doubtful. None of the slips were good on bone dry body. For leather hard body the limits of composition of good slips found in this group lie between:

M. G. R. English China Clay	35 to 55	
Brandywine Feldspar	5 to 20	
Ohio Flint	30 to 45	
Pikes No. 20 English Ball Clay	10	Constant
Carbonate of Soda	1	

SERIES 50.

(On Biscuit)

Constant: Georgia Kaolin, 15; Tenn. Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 5		Cone 7		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
344	60	15	Crazed	Crazed	Crazed	Crazed	Good	Good
345	55	20	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed
346	50	25	Crazed	Crazed	Crazed	Good	Crazed	Good
347	45	30	Crazed	Good	Good	Good	Good	Good
348	40	35	Crazed	Good	Crazed	Good	Good	Good
349	35	40	Good	Good	Good	Good	Good	Good
350	30	45	Crazed	Good	Crazed	Good	Good	Good
351	25	50	Good	Good	Good	Good	Good	Good

Crazing decreases with decrease in flint and increase in Cornwall stone. Crazing also decreases with increase in temperature. All are opaque at Cone 4. No. 351 is translucent at Cone 7. Slips 349 to 351 are translucent

at Cone 9. No. 351 without glaze has a beautiful porcelain texture at cones 7 and 9. Its texture is a beautiful imitation of blue white marble.

Group IV. Series 51 to 56.

SERIES 51.

(On Biscuit)

Constant: N. C. Kaolin, 15; Tenn. Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 6		Cone 7		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
352	60	15	Crazed	Crazed	Crazed	Crazed	Crazed	Good
353	55	20	Crazed	Crazed	Crazed	Crazed	Crazed	Good
354	50	25	Crazed	Crazed	Crazed	Good	Good	Good
355	45	30	Crazed	Good	Good	Good	Good	Good
356	40	35	Crazed	Good	Crazed	Good	Good	Good
357	35	40	Good	Good	Good	Good	Good	Good
358	30	45	Crazed	Good	Crazed	Good	Good	Good
359	25	50	Good	Good	Good	Good	Good	Good

Aside from crazing, slips fit the body very well. Crazing decreases with decrease in flint, increase in Cornwall stone and increase in temperature. All are opaque at Cone 6. Slips 357 to 359 are vitrified at Cone 7. Nos. 355 to 359 are vitrified at Cone 9. Slip No. 359 has a beautiful parian marble texture at cones 7 and 9. Series not so white as Series 50.

SERIES 52.

(On Biscuit)

Constant: N. C. Kaolin, 25; Tenn. Ball, 10; Carbonate of Soda, 1.

No	Flint	Eng. C. Stone	Cone 6		Cone 7		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
360	50	15	Crazed	Good	Good	Good	Good	Good
361	45	20	Crazed	Good	Cracked	Good	Cracked	Good
362	40	25	Good	Good	Good	Good	Good	Good
363	35	30	Good	Good	Good	Good	Good	Good
364	30	35	Good	Good	Cracked	Good	Good	Good
365	25	40	Good	Good	Good	Good	Cracked	Good
366	20	45	Good	Good	Cracked	Good	Cracked	Good
367	15	50	Good	Good	Good	Good	Good	Good

Slips have a slight tendency to crack as the temperature of burning increases. All glazed slips were sound. All are opaque at Cone 6. Slips 365 to 367 are vitrified at Cone 7. Slips 363 to 367 are vitrified at Cone 9.

SERIES 53.

(On Biscuit)

Constant: N. C. Kaolin, 35; Tenn. Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng C. Stone	Cone 6		Cone 7		Cone 9	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
368	45	10	Cracked	Good	Cracked	Good	Cracked	Good
369	40	15	Cracked	Good	Cracked	Good	Cracked	Good
370	35	20	Cracked	Good	Cracked	Cracked	Cracked	Good
371	30	25	Cracked	Good	Good	Good	Good	Good
372	25	30	Cracked	Good	Good	Good	Good	Good
373	20	35	Good	Good	Good	Good	Cracked	Good
374	15	40	Good	Good	Good	Good	Good	Good
375	10	45	Cracked	Cracked	Cracked	Good	Cracked	Good

Cracking in this series has increased over that observed in Series 52. Cracking has evidently increased with increase in clay. Cracking decreases with decrease in flint and increase in Cornwall stone, but this is not borne out in all cases. Slips are all opaque at Cone 6. Slips 373 to 375 are vitrified at Cone 7. Nos. 371 to 375 are vitrified at Cone 9.

SERIES 54.

(On Biscuit)

Constant: N. C. Kaolin, 45; Tenn. Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 6		Cone 7		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
376	40	5	Cracked	Good	Cracked	Good	Cracked	Cracked
377	35	10	Cracked	Cracked	Cracked	Cracked	Cracked	Good
378	30	15	Cracked	Good	Cracked	Cracked	Cracked	Good
379	25	20	Cracked	Good	Cracked	Good	Cracked	Good
380	20	25	Cracked	Good	Cracked	Good	Cracked	Cracked
381	15	30	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
382	10	35	Cracked	Cracked	Cracked	Good	Cracked	Cracked

Cracking has increased. Glaze is not able to prevent cracking though it reduces it. Slips are all opaque at Cones 6 and 7. Slip 382 is translucent at Cone 8.

SERIES 55.

(On Biscuit)

Constant: N. C. Kaolin, 55; Tenn. Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 6		Cone 7		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
383	5	30	Good	Cracked	Good	Good	Good	Cracked
384	10	25	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
385	15	20	Good	Cracked	Cracked	Cracked	Good	Cracked
386	20	15	Cracked	Cracked	Good	Cracked	Good	Cracked
387	25	10	Good	Cracked	Cracked	Cracked	Good	Cracked
388	30	5	Cracked	Cracked	Cracked	Cracked	Good	Cracked

Cracking has steadily increased with increase of clay. Increase of temperature seems to increase cracking. All slips are opaque at Cone 8.

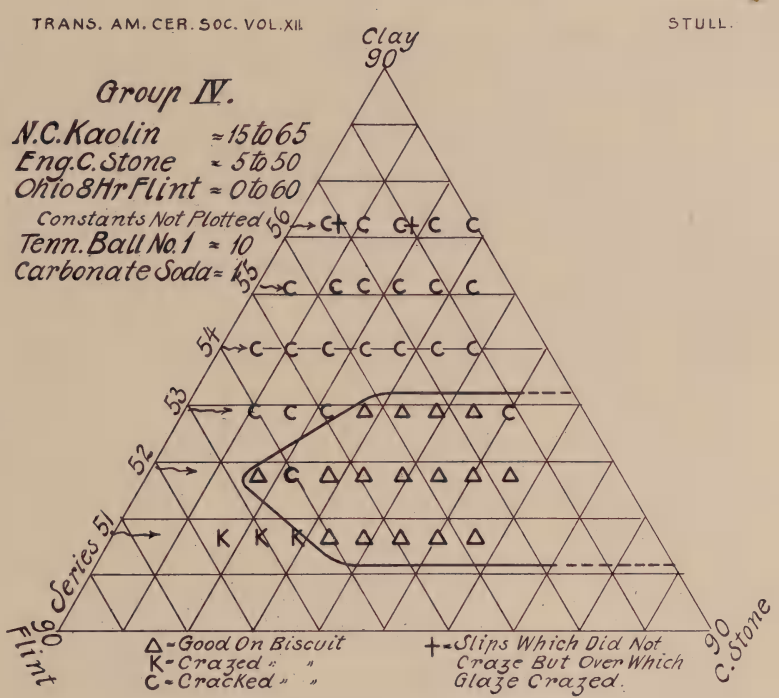
SERIES 56.

(On Biscuit)

Constant: N. C. Kaolin, 65; Tenn. Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 3		Cone 5		Cone 7	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
389	20	5	Cracked	Crazed	Crazed	Good	Good	Cracked
390	15	10	Cracked	Good	Cracked	Cracked	Cracked	Good
391	10	15	Cracked	Crazed Cracked	Cracked	Good	Cracked	Good
392	5	20	Cracked	Cracked	Cracked	Cracked	Cracked	Good
393	0	25	Cracked	Good	Cracked	Cracked	Cracked	Good

Slips are not cracked so badly as in Series 55, but probably due to the fact that the slips in Series 56 are burned at correspondingly lower temperatures. Slips do not craze but glaze shows crazing at Cone 2, in fine zig-zag lines.



Conclusions on Group IV.

Crazing: Crazing of slips decreases with decrease in flint and increase in clay or Cornwall stone, or both. Increasing clay is more effective in reducing crazing than increasing Cornwall stone. With flint constant, decreasing clay and increasing Cornwall stone increases crazing. These observations are the same as those noted in the three preceding groups, which shows the similar influences of feldspar and Cornwall stone upon crazing of slips. With respect to the temperature of burning the opposite is true. In Group IV, increasing burning temperature decreases crazing.

Cracking is due to high content of clay. Reducing clay and increasing flint or Cornwall stone, or both, reduces cracking. In one series evidence is presented that

increasing Cornwall stone is more effective in reducing cracking than increasing flint, though this is not borne out in all cases and is opposite to what was observed in Group I, with respect to flint and feldspar. Experience in the manufacture of enamel brick shows that replacement of Cornwall stone by flint reduces cracking.

In comparing Groups I and IV it is evident that the replacement of feldspar by Cornwall stone has given a smaller field of good slips on biscuit body, and has reduced crazing and increased cracking.

The limits of composition of good slips on biscuit body found in this group are:

North Carolina Kaolin	15 to 35	
English Cornwall Stone	15 to 50	
Ohio Flint	15 to 45	
Tennessee Ball Clay No. 1	10	Constant
Carbonate of Soda	1	Constant

Group V. Series 57 to 62.

SERIES 57.

(On Biscuit)

Constant: N. C. Kaolin, 15; English Ball No. 1, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 3		Cone 5		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
394	60	15	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed
395	55	20	Crazed	Crazed	Crazed	Crazed	Crazed	Good
396	50	25	Crazed	Crazed	Crazed	Crazed	Crazed	Good
397	45	30	Crazed	Good	Crazed	Crazed	Good	Good
398	40	35	Crazed	Crazed	Crazed	Good	Crazed	Good
399	35	40	Crazed	Good	Good	Good	Good	Good
400	30	45	Crazed	Good	Crazed	Good	Good	Good
401	25	50	Good	Good	Crazed	Good	Good	Good
402	20	55	Good	Good	Crazed	Good	Good	Good

Slips craze quite badly. Glaze tends to prevent crazing of slips. Crazing decreases with decrease in flint, increases in Cornwall stone and increase in temperature. All are opaque at Cone 4. Nos. 401 and 402 are vitrified at Cone 6. Slips 399 to 402 vitrified at Cone 8.

SERIES 57.

(On Bone Dry)

No.	Cone 3		Cone 5		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
394	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed
395	Crazed	Crazed	Crazed	Good	Crazed	Good
396	Crazed	Crazed	Crazed	Crazed	Crazed	Good
397	Crazed	Good	Crazed	Good	Crazed	Good
398	Crazed	Good	Crazed	Good	Cracked	Cracked
399	Good	Good	Good	Good	Good	Good
400	Good	Good	Good	Good	Good	Good
401	Cracked	Good	Cracked	Good	Cracked	Cracked
402	Cracked	Good	Cracked	Cracked	Cracked	Cracked

Slips fit quite well. Crazing is practically the same as that observed in the same slips on biscuit. Cracking is slight.

SERIES 58.

(On Biscuit)

Constant: N. C. Kaolin, 25; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 4		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
403	50	15	Good	Good	Good	Good	Good	Good
404	45	20	Good	Good	Good	Good	Good	Good
405	40	25	Good	Good	Good	Good	Good	Good
406	35	30	Good	Cracked	Cracked	Good	Good	Good
407	30	35	Cracked	Cracked	Good	Good	Good	Good
408	25	40	Good	Good	Good	Good	Good	Cracked
409	20	45	Good	Good	Good	Good	Good	Good
410	15	50	Good	Good	Good	Good	Good	Good

Slips have slight tendency to crack when applied too thick, otherwise they seem to fit perfectly. All are opaque at Cone 6. Slips 407 to 410 are vitrified at Cone 8.

SERIES 58.

(On Bone Dry)

No.	Cone 4		Cone 6		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
403	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
404	Good	Cracked	Cracked	Cracked	Cracked	Cracked
405	Good	Good	Cracked	Cracked	Cracked	Good
406	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
407	Good	Good	Cracked	Cracked	Cracked	Good
408	Cracked	Cracked	Cracked	Good	Good	Good
409	Cracked	Cracked	Cracked	Cracked	Good	Cracked
410	Cracked	Cracked	Cracked	Cracked	Good	Cracked

Slips crack slightly in fine lines. Some are very good. These slips would probably work well for spraying on bone dry body.

SERIES 59.

(On Biscuit)

Constant: N. C. Kaolin, 35; English Ball No. 20, 10; Carbonate of Soda, 1.

No	Flint	Eng. C. Stone	Cone 2		Cone 7		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
411	45	10	Good	Cracked	Cracked	Cracked	Good	Cracked
412	40	15	Good	Good	Good	Cracked	Good	Good
413	35	20	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
414	30	25	Cracked	Cracked	Good	Cracked	Cracked	Cracked
415	25	30	Good	Cracked	Cracked	Cracked	Cracked	Cracked
416	20	35	Good	Cracked	Cracked	Cracked	Cracked	Cracked
417	15	40	Good	Cracked	Cracked	Cracked	Good	Cracked
418	10	45	Good	Good	Good	Good	Good	Good

Cracking has increased more than in Series 58. Cracking evidently increases with increase in clay. Replacement of flint by Cornwall stone does not seem to influence cracking.

SERIES 59.
(On Bone Dry)

No.	Cone 3		Cone 7		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
411	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
412	Good	Cracked	Cracked	Cracked	Cracked	Cracked
413	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
414	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
415	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
416	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
417	Cracked	Cracked	Good	Cracked	Cracked	Cracked
418	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked

Cracking has increased markedly over Series 58 on bone dry. As a rule the glaze reduces cracking.

SERIES 60.
(On Biscuit)

Constant: N. C. Kaolin, 45; English Ball No. 20, 10; Carbonate of Soda, 1.

No.	Flint	Spar.	Cone 3		Cone 7		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
419	35	10	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
420	30	15	Good	Cracked	Good	Cracked	Cracked	Cracked
421	25	20	Good	Cracked	Good	Cracked	Good	Cracked
422	20	25	Good	Cracked	Good	Cracked	Good	Cracked
423	15	30	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
424	10	35	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked

Slips crack badly. Difference in composition and heat treatment do not seem to influence the degree of cracking.

SERIES 61.
(On Biscuit)

Constant: N. C. Kaolin, 55; English Ball No. 20, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 5		Cone 7		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
425	30	5	Cracked	Cracked	Good	Cracked	Good	Cracked
426	25	10	Cracked	Cracked	Cracked	Cracked	Good	Cracked
427	20	15	Cracked	Cracked	Cracked	Cracked	Good	Cracked
428	15	20	Good	Cracked	Cracked	Cracked	Cracked	Cracked
429	10	25	Good	Cracked	Cracked	Cracked	Cracked	Cracked
430	5	30	Good	Cracked	Cracked	Cracked	Cracked	Cracked

Slips crack and curl up a little. Cracking seems to increase by replacement of flint by Cornwall stone.

SERIES 61.
(On Leather Hard)

No.	Cone 5		Cone 7		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
425	Good	Good	Good	Good	Good	Cracked
426	Good	Good	Good	Flaked	Good	Cracked
427	Good	Good	Good	Good	Good	Cracked
428	Good	Good	Good	Flaked	Cracked	Cracked
429	Flaked	Cracked	Flaked	Flaked	Cracked	Cracked
430	Good	Flaked	Good	Flaked	Cracked	Cracked

Slips were applied a little too thick. Some flaking occurs but not bad. Glaze flakes loose from slips in a few cases.

SERIES 62.
(On Biscuit)

Constant: N. C. Kaolin, 65; English Ball No. 20, 10; Carbonate of Soda, 1.

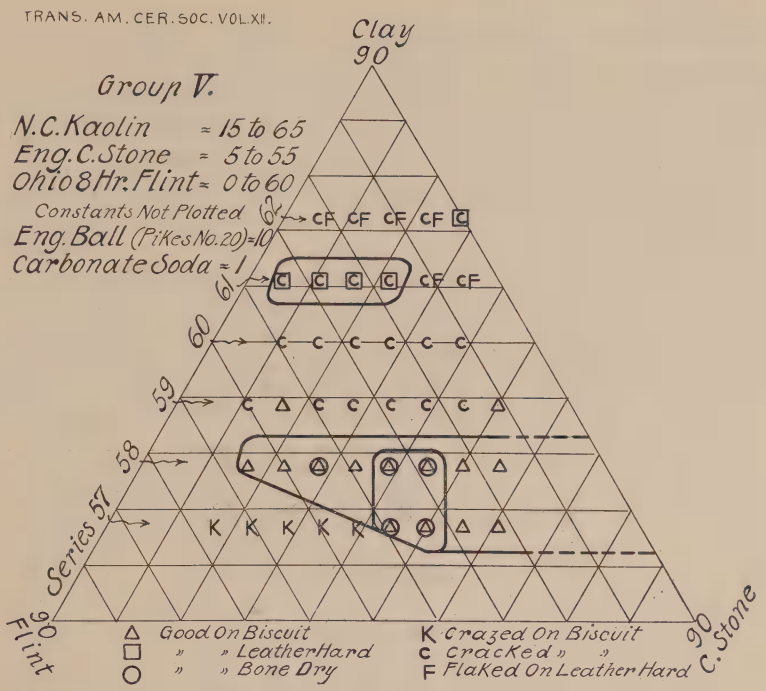
No.	Flint	Eng. C. Stone	Cone 5		Cone 7		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
431	20	5	Good	Cracked	Good	Cracked	Good	Cracked
432	15	10	Good	Cracked	Good	Cracked	Good	Cracked
433	10	15	Cracked	Cracked	Cracked	Cracked	Good	Cracked
434	5	20	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
435	0	25	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked

Series 62 on biscuit: This series cracks worse than any other series in the group. Slips curl up some.

SERIES 62.
(On Leather Hard)

No.	Cone 5		Cone 7		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
431	Good	Flaked	Flaked	Flaked	Flaked	Flaked
432	Flaked	Good	Flaked	Flaked	Flaked	Flaked
433	Flaked	Flaked	Good	Flaked	Flaked	Flaked
434	Good	Flaked	Good	Flaked	Cracked	Flaked
435	Good	Flaked	Good	Flaked	Good	Good

Slips flake some. Glaze also flakes a little. Slip No. 435, however, is very good at Cone 8.



Conclusions on Group V.

Crazing and Cracking: The observations on crazing and cracking in Group V are the same as those of Group IV.

Flaking: Flaking on leather hard body during burning increases with increase in clay. Reducing clay and increasing flint or Cornwall stone, or both, reduces flaking during burning. The opposite is true of flaking in dipping.

Comparing Groups V and IV shows a decrease in number of good slips on biscuit body by substituting Pikes No. 20 English ball clay for Tennessee No. 1 ball clay. Cracking and crazing have increased. (See comparison of Groups I and II.)

In comparing Groups V and II it is shown that the

substitution of Cornwall stone for feldspar has increased crazing and flaking. Cracking remains practically the same. The fields of good slips on biscuit and leather hard bodies are smaller. A few good slips on bone dry body appear in Group V which are lacking in Group II.

The limits of composition of good slips found in Group V are:

	On Biscuit	On Bone Dry	On Leather Hard
North Carolina Kaolin....	15 to 25	15 to 25	55 to 65
English Cornwall Stone...	15 to 55	25 to 45	5 to 25
Ohio Flint	15 to 50	25 to 40	0 to 30
Carbonate of Soda.....	10	10	10 } Constant
Pikes No. 20 English Ball.	1	1	1 }

Group VI. Series 63 to 68.

SERIES 63.

(On Biscuit)

Constant: English China, 15; English Ball No. 20, 10; Carbonate of Soda, 1.

No.	Flint	Eng C. Stone	Cone 3		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
436	60	15	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed
437	55	20	Good	Crazed	Good	Crazed	Good	Crazed
438	50	25	Crazed	Crazed	Good	Crazed	Good	Good
439	45	30	Good	Crazed	Good	Crazed	Good	Good
440	40	35	Crazed	Crazed	Good	Good	Good	Good
441	35	40	Good	Crazed	Good	Good	Good	Good
442	30	45	Good	Crazed	Good	Good	Good	Good
443	25	50	Good	Crazed	Good	Good	Good	Good
444	20	55	Good	Good	Good	Good	Good	Good

Slips high in flint craze. Glaze tends to prevent crazing of slips. Crazing decreases with decrease in flint, increase in Cornwall stone and increase in temperature. All slips are opaque at Cone 3. Slips 438 to 444 are vitrified at Cone 9.

SERIES 63.

(On Bone Dry)

No.	Cone 3		Cone 6		Cone 8	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
436	Crazed	Crazed	Crazed	Crazed	Crazed	Crazed
437	Crazed	Crazed	Crazed	Crazed	Crazed	Good
438	Good	Crazed	Good	Good	Good	Good
439	Good	Crazed	Good	Crazed	Good	Good
440	Good	Crazed	Good	Crazed	Good	Good
441	Good	Crazed	Good	Good	Good	Good
442	Good	Crazed	Good	Good	Good	Cracked
443	Good	Good	Cracked	Cracked	Cracked	
444	Good	Good	Good	Good	Crazed	Good

Crazing of slips practically the same as that observed in the same series on biscuit. Slips fit body very good, though not perfectly.

SERIES 64.

(On Biscuit)

Constant: English China, 25; English Ball No. 20, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 3		Cone 6		Cone 8	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
445	50	15	Good	Crazed	Good	Crazed	Good	Crazed
446	45	20	Good	Crazed	Good	Crazed	Good	Crazed
447	40	25	Good	Crazed	Good	Crazed	Good	Good
448	35	30	Good	Good	Good	Good	Good	Good
449	30	35	Good	Good	Good	Good	Good	Good
450	25	40	Good	Good	Good	Good	Good	Good
451	20	45	Good	Good	Good	Good	Good	Good
452	15	50	Good	Good	Good	Good	Good	Good

Slips fit body perfectly aside from crazing. Crazing decreases with decrease in flint and increase in Cornwall stone. All are opaque at Cone 2. Slips 448 to 452 are vitrified at Cone 6. Slips 446 to 452 are vitrified at Cone 7.

SERIES 64.

(On Bone Dry)

No.	Cone 2		Cone 6		Cone 7	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
445	Good	Crazed	Good	Crazed	Cracked	Crazed
446	Cracked	Cracked	Cracked	Crazed	Cracked	Crazed
447	Cracked	Crazed	Cracked	Crazed	Cracked	Good
448	Cracked	Crazed	Cracked	Good	Cracked	Cracked
449	Crazed	Crazed	Cracked	Cracked	Cracked	Cracked
450	Cracked	Cracked	Cracked	Cracked	Cracked	Cracked
451	Cracked	Good	Good	Good	Good	Good
452	Good	Cracked	Cracked	Good	Cracked	Good

The cracking, which is of the so-called "crowsfoot" type, is not bad. Variation in composition and temperature do not seem to influence the degree of cracking. No. 451 is very good at Cones 6 and 7.

SERIES 64.

(On Leather Hard)

No.	Cone 2		Cone 6		Cone 7	
	Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
445	Flaked	Flaked	Flaked	Flaked	Flaked	Flaked
446	Good	Flaked	Good	Flaked	Good	Flaked
447	Good	Good	Good	Good	Good	Flaked
448	Good	Good	Good	Good	Good	Flaked
449	Good	Good	Good	Good	Flaked	Flaked
450	Good	Good	Good	Flaked	Good	Flaked
451	Good	Good	Good	Good	Good	Good
452	Good	Good	Good	Good	Good	Good

Flaking appears to decrease with decrease of flint and increase in Cornwall stone. Glaze tends to reduce the degree of flaking, but not to overcome it. A subsequent examination of duplicate trials showed that slips were imperfectly bonded before burning since slips could be flaked off in small patches by pressing with the thumb nail.

SERIES 65.

(On Leather Hard)

Constant: English China, 35; English Ball No. 20, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 4		Cone 6		Cone 7	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
453	45	10	Good	Good	Good	Flaked	Good	Flaked
454	40	15	Good	Flaked	Flaked	Flaked	Good	Good
455	35	20	Good	Flaked	Good	Flaked	Good	Flaked
456	30	25	Good	Good	Good	Good	Good	Good
457	25	30	Good	Good	Good	Good	Good	Good
458	20	35	Good	Good	Good	Good	Good	Good
459	15	40	Good	Good	Good	Good	Good	Good
460	10	45	Good	Good	Good	Good	Good	Good

Flaking is less than in Series 64. Flaking decreases with decrease in flint and increase in Cornwall stone. Slips 456 to 466 are good hard slips at Cone 7. No. 460 is a dense white porcelain.

SERIES 66.

(On Leather Hard)

Constant: English China, 45; English Ball No. 20, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 2		Cone 6		Cone 7	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
461	40	5	Good	Good	Good	Good	Good	Good
462	35	10	Good	Good	Good	Good	Good	Good
463	30	15	Good	Flaked	Flaked	Flaked	Good	Flaked
464	25	20	Good	Good	Good	Good	Good	Good
465	20	25	Good	Good	Good	Good	Good	Good
466	15	30	Good	Good	Good	Good	Good	Good
467	10	35	Good	Good	Good	Good	Good	Good

Slips fit body very well. Slip No. 463 is the only one that showed any signs of flaking. Glaze has a tendency to flake on the slips. Slips 464 to 467 are excellent as to fit, color and hardness.

SERIES 67.

(On Leather Hard)

Constant: English China, 55; English Ball No. 20, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 4		Cone 6		Cone 7	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
468	30	5	Good	Good	Good	Good	Good	Good
469	25	10	Good	Good	Good	Good	Good	Good
470	20	15	Good	Good	Good	Good	Good	Good
471	15	20	Good	Good	Good	Good	Good	Good
472	10	25	Good	Good	Good	Good	Good	Good
473	5	30	Good	Good	Good	Good	Good	Good

All slips fit body perfectly. No cracking or flaking could be detected. This is the best series in the group. Slips 470 to 473 are especially good at Cones 6 and 7.

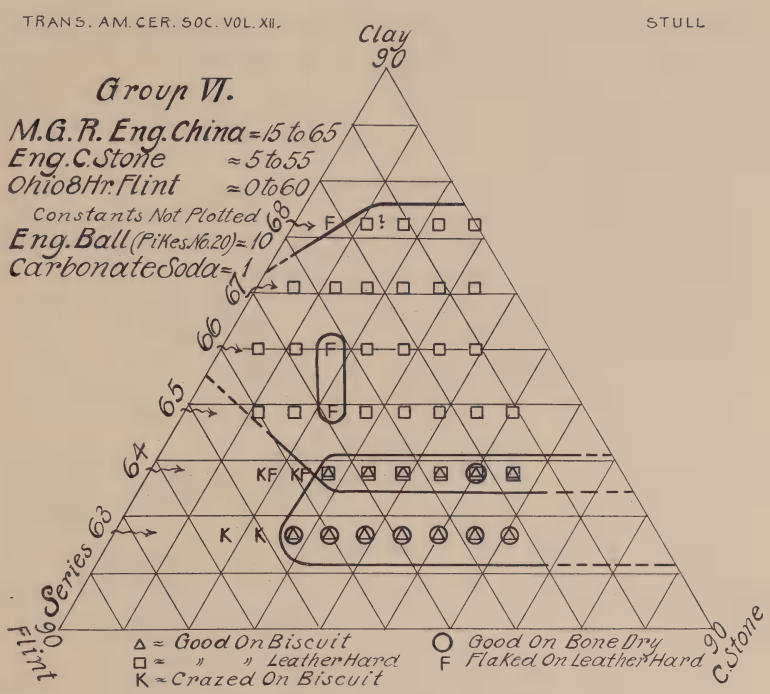
SERIES 68.

(On Leather Hard)

Constant: English China, 65; English Ball, 10; Carbonate of Soda, 1.

No.	Flint	Eng. C. Stone	Cone 4		Cone 6		Cone 7	
			Unglazed	Glazed	Unglazed	Glazed	Unglazed	Glazed
474	20	5	Good	Good	Flaked	Flaked	Flaked	Flaked
475	15	10	Good	Flaked	Flaked	Flaked	Flaked	Flaked
476	10	15	Good	Good	Good	Good	Good	Good
477	5	20	Good	Good	Good	Good	Good	Good
478	0	25	Good	Good	Good	Good	Good	Good

Slips high in clay and flint have a tendency to flake. Decrease of flint and increase of Cornwall stone has reduced flaking. Slips 477 and 478 are very good.



Conclusions on Group VI.

Crazing: Practically the same conclusions on crazing of the slip apply in this group as those observed in Groups IV and V.

Cracking: Very little cracking occurred in slips applied to bone dry body. No cracking occurred in slips applied to biscuit and leather hard bodies.

Flaking: Slips both low and high in clay showed a tendency to flake. Evidently slips low in clay were imperfectly bonded before burning. Flaking decreases with decrease in flint and increase in Cornwall stone.

A comparison of Groups VI and V shows that the substitution of M. G. R. English China clay for North Carolina kaolin has decreased crazing, cracking and flaking. The fields of good slips on biscuit body are practi-

cally the same size. A larger number of good slips appear on bone dry body, and the field of good slips on leather hard body has expanded to a comparatively large area. The slips are also superior in whiteness and vitrify at lower temperatures.

A comparison of Groups VI and III shows that the substitution of English Cornwall stone for feldspar has decreased crazing, cracking and flaking. The fields of good slips on biscuit and leather hard bodies have increased and good slips on bone dry were obtained, which are absent in Series III.

The limits of composition of good slips found in Group VI are:

	On Biscuit	On Leather Hard	On Bone Dry
M. G. R. English China Clay.	15 to 25	25 to 65	15 to 25
English Cornwall Stone.....	25 to 55	5 to 50	25 to 55
Ohio Flint	15 to 50	0 to 45	20 to 50
Pikes No. 20 Eng. Ball Clay.	10	10	10
Carbonate of Soda	1	1	1

GENERAL DEDUCTIONS.

From previous practical experience in the manufacture of enamel brick and from the foregoing investigations, the following rules are given for overcoming defects in enamel brick slips:

Defects Arising in the Application of the Slips and Remedies for the Same.

Principal Defects	Causes	Remedies
Pinholes	1. Using freshly made slips.	1. Age slips a week or more.
	2. Dust on the surface of brick.	2. Remove all dust or scrub the surfaces to be dipped.
	3. Pinholes in the surface of the brick.	3. Scrub surfaces to be dipped.
	4. Bad dipping.	4. (See Fig. 1, p. 717.)
Cracking	5. Too high content of clay in slip.	5. Reduce clay and increase the non-plastic portion, or add a soluble material as carbonate of soda, borax or silicate of soda.
	6. Slips too high in China clay or kaolin.	6. Decrease China clay or kaolin and increase ball clay, or add a soluble material.
	7. Allowing leather hard body to get too dry before dipping.	7. Dip brick in a softer condition.
	8. Applying slip too thick.	8. Do not apply slip over .05 of an inch thick.
	9. Too fine grinding of slip.	9. Blunge slips instead of grinding.
Flaking	10. Using slips too low in clay.	10. Increase clay and decrease non-plastic portion.
	11. Slips too high in China clay or kaolin.	11. Decrease China clay or kaolin and increase ball clay.
	12. Oil or dust on dipping surface.	12. Scrub surfaces to be dipped.
	13. In dipping on leather hard; dipping before brick have hardened sufficiently.	13. Allow brick to reach a firm leather hard condition before dipping.

Slip Defects Arising in Burning and Remedies for the Same.

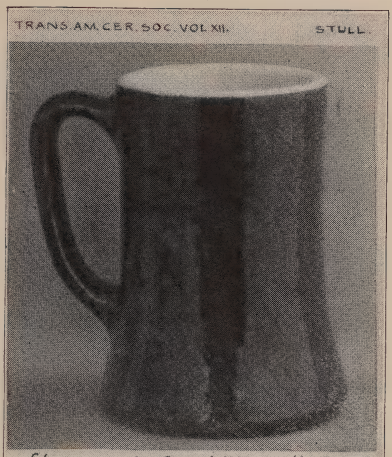
Principal Defects	Causes	Remedies
Crazing	14. Slips too high in flint.	14. Reduce flint and increase clay, feldspar or Cornwall stone.
	15. Slips too high in feldspar or Cornwall stone.	15. Reduce feldspar or Cornwall stone and increase clay.
	16. With feldspar as a flux; burning slips at too high a temperature.	16. Reduce burning temperature.
	17. With Cornwall stone as a flux; burning slips at too low a temperature.	17. Increase burning temperature.
Cracking	18. Too high content of clay in slips.	18. Reduce clay and increase flint, Cornwall stone or feldspar.
	19. Too high content of feldspar or Cornwall stone in slips.	19. Reduce feldspar or Cornwall stone and increase flint.
Flaking	20. Dipping slips too thick.	20. Same as No. 8.
	21. Too high content of clay in slips.	21. Reduce clay and increase Cornwall stone, flint or feldspar.
	22. Too high content of feldspar in slips.	22. Reduce feldspar and increase Cornwall stone.
	23. Too high content of flint in slips.	23. Reduce flint and increase Cornwall stone.
	24. Burning slips at too high a temperature.	24. Reduce burning temperature.

SLIPS TESTED AS ENGOBES FOR STONEWARE.

The problem of producing a slip or engobe to be used as a white lining for stoneware was confronted. Slips No. 292, 298, 464 and 470 were selected as the starting point. These slips were applied to three different stoneware clays, viz.: Whitehall clay from Whitehall, Ill., having a comparatively high shrinkage; Macomb clay of medium shrinkage from Macomb, Ill.; Bloomingdale clay having a comparatively low shrinkage from Bloomingdale, Ind.

Trials were made in the form of cups, jiggered in one piece. Cups were taken from the molds, finished leather

hard, and slips applied to the inside in two coats. Over this a clear glaze was applied in one coat. The slip and glaze were scraped off at the outside rim. A brown glaze was applied to the outside by sinking the cup down into



Stoneware Cup With White Engobe And Clear Glaze Inside And Brown Glaze Outside.

the glaze until the brown glaze touched the white slip and glaze extending over the rim. The cups were dried and burned at Cone 3. All four slips worked perfectly on all three stoneware bodies.

DISCUSSION.

Mr. Ramsay: There is a lot I would like to say on this subject, as it is an interesting one, but the trouble we have in the enamel brick business is not with the slips but in the cost of manufacture and results out of kilns.

I know Mr. Stull has put a good deal of time and work on his paper, and I agree with him on many of his results. To get a slip as near to the clays as possible you have to use lime, and when that is added it changes the results entirely. He made the claim that the slip will peal off with the dry clay. I would like to take exception to the

remark for the reason that ball clay will not come off. With China clay it will come off, but by a mixture of both it will not come off.

Mr. Stull: I do not think Mr. Ramsay's statement is antagonistic to what has been brought out in my paper. If a slip is high enough in ball clay it will cling to the body. Enamel brick makers as well as potters are limited in the amount of ball clay they can use on account of the bad color it imparts. For this reason I used ten per cent ball clay as the high limit in all slips.

It is quite essential to have some ball clay in the slip, but as a rule the less ball clay present the better color you get. My experience shows that a slip made from ball clay will stick very well but will crack badly. Ball clay possesses better adhesive qualities than China clay or kaolin, and seems to adjust itself better to the body both in drying and burning.

Mr. Ashley: I think to slightly increase the China clay slip by adding a small quantity of silicate of soda, will give some of the general characteristics of ball clay.

Mr. Ramsay: It may be in certain respects. If you add a certain percentage of silicate of soda you destroy the working qualities as regards the dipping. I suppose the idea is to decrease the water content and that only affects the drying shrinkage. There is no effect afterwards, of course, and I think the difference is so slight that it is hardly worth trying.

Mr. Stull: My experience in using silicate of soda was that it caused the slip to settle very rapidly and cake hard at the bottom. It requires constant agitation to keep the slip in suspension. Perhaps I was using too high a percentage, although it was only 3/8 of one per cent, however.

Mr. Ashley: I would suggest that even 1/10 of one per cent of silicate of soda acts very vigorously on clay, and we should experiment with 1/100 of one per cent rather than 1/10.

Mr. Worcester: I would like to ask Mr. Stull if he has studied the hardness of these slips with the various contents of spar. In some work we have been doing at Ohio State that was one of the requirements to produce a hard or nearly steel hard slip and I, of course, am very much interested, and was wondering if Mr. Stull had observed this point in particular or at all.

Mr. Stull: When each slip was shaken up and turned out of the can before dipping, a little of it was cast into trials, 1¾″ long, ½″ wide and ¼″ thick. These were placed in the sagger and burned with the dipped trials and used to determine the porosity. It was desirable to know what was the limit of porosity for these slips which would withstand the freezing test. That part of the work is under way at the present time.

Mr. Stover: I would like to ask what percentage of absorption you got, or was it around 1%? You spoke of making trials for absorption for your slips and that would follow in your paper. I happen to be looking along that line just now and would like to know.

Mr. Stull: There are two methods of determining the porous nature of brick. One is the percentage of absorption and one is the percentage of porosity. The absorption, as we know, is usually determined by weighing the brick dry then soaking it 48 hours and weighing it again. By observing the increase in weight and dividing that increase by the weight of the brick gives what is called percentage absorption. The percentage porosity is approximately 2½ times percentage absorption. The porosity of these slips was determined by Prof. Purdy's formula. The porosities of the slips have varied according to the kind and amount of flux and the temperature of burning. Perfect fitting slips were obtained from as soft as chalk up to a hard vitrified and glossed condition.

Mr. Stover: And do you not remember in figures what the result was?

Mr. Stull: No, I do not.

THE TECHNICAL CONTROL OF THE COLLOID MATTER IN CLAYS.*

BY

HARRISON EVERETT ASHLEY, Pittsburg, Pa.

It is believed that the year's laboratory work on the colloid matter of clays has resulted in obtaining so definite an understanding of its chemical nature that hereafter it will be possible to control positively the colloid matter in any clay or clay mixture.[1]

The year's results may be concisely and strikingly summed up by saying that the chemical reactions of the colloid matter of clay are remarkably similar to those of fats and soaps,[2] that the conditions of solubility and insolubility are remarkably parallel, but that the colloid matter of clay is probably more readily acted upon. Thus, in a general way, the sodium, potassium and ammonium salts of the fatty acids are soluble in water; and the sodium, potassium and ammonium sols of clay colloids are soluble in water. The free fatty acids are insoluble in water[3] and the acid gels of clay are insoluble in water. The bivalent and trivalent bases form insoluble salts with soaps and insoluble gels with clay colloids. Both soaps and clay sols may be salted out of solution by dissolving in

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*By permission of the Director of the United States Geological Survey.

[1] This paper will be more completely understood if the reader is familiar with the writer's papers of last year, but the endeavor will be made to have it sufficiently complete, without repetition, to be clear. Trans. 11, 530-595 (1909). U. S. G. S., Bulletin 388 (1909).

[2] Keppeler [Z. fur angew. Chemie, 22 [2], 526-7 (1909 March 12)], has noted a paraMelism between the emulsification of fats by soaps and the effects produced by salts of acids of high molecular weights upon clays, but does not seem to have carried the idea further.

[3] Although the fatty acids occurring in fats are insoluble in water, the simplest members of the chemical series to which they belong are soluble. This will be discussed further under oxalic acid and tannic acid.

the solution chemical salts that have more affinity for water than have the soaps or gels so salted out.

The proof of these conceptions is that they are not inconsistent with the known facts about clays, that they have proved a most helpful and suggestive guide in planning these investigations, and that they have never misled.

A few representative cases of the clay colloid reactions will be thoroughly described, and then special applications will be considered.

THEORY.

We will first consider a clay composed of granular matter, calcium gels, and a very little calcium sulphate. Such a clay is the Georgia sagger clay (kaolin) of the Hall Clay Co.[4] Into each of four glass stoppered 100 cc. graduated tubes was put 98 cubic centimeters distilled water, then five grams of the clay. This made a total volume of 100 cc. The tubes were rotated on the shaking machine (Fig. 1) for one hour and allowed to stand. They then contained as follows:

Tube	A	B	C	D
cc. clear liquid	82	82	83	81
cc. sediment	18	18	17	19

The hydrogen ion concentration of the clear liquid

[4] Five grams of this clay was rotated with 98 cc. water for one hour and allowed to settle over night. Qualitative tests on the clear liquid showed a little chlorine, a little sulphuric anhydride, no iron or aluminum, a little calcium and a very little alkali. Another 5 gram portion was similarly treated with 97 cc. water and 1 cc. hydrochloric acid (S. G. 1.20). Qualitative tests showed a little sulphuric anhydride, no iron or aluminum, very decidedly more calcium than the water extract, and about the same test for alkalis. Magnesia was not treated for. More painstaking tests on the extract from larger amounts of clay would doubtless have shown other constituents. These tests were sufficient, however, to show that the soluble salts are mainly a trace of alkali chlorides and calcium sulphate. The action of hydrochloric acid on the clay I consider to have been $2\,H\,Cl + Ca\ gel = Ca\,Cl_2 + H_2$ gel, i. e., easily removable calcium was taken from the gel and hydrogen left in its place.

was 1.10^{-5} normal.[5] 75 cc. of the clear liquid was siphoned off, replaced by pure water, and the tube again shaken and allowed to stand. This was equivalent to diluting the first portion of liquid to four times its original volume. This was repeated until the equivalent of a dilution of 8,000 times was reached. For tube D the effect was measured as follows:

Dilution	0	4	20	100	500	2000	8000
cc. clear	85	84	81.5	82	81	81	....
cc. sediment	15	16	18.5	18	19	19	....
H ion conc., normality	1.10^{-5}	..	1.10^{-5}	1.10^{-5}	...	1.10^{-5}	....

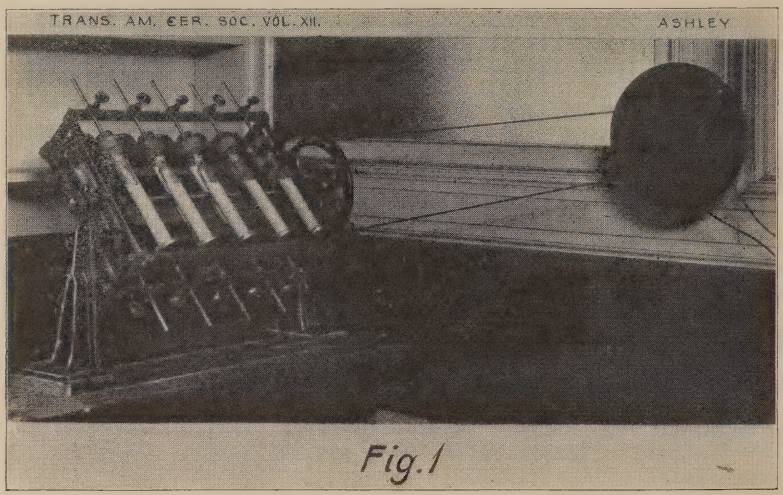


Fig. 1

This increase in bulk of sediment has been noticed in other cases where a clay and an original portion of liquid have been repeatedly shaken without any replacements of

[5] The acid or alkaline strength of any liquid is given by the concentration of the hydrogen ions; for example, tenth normal hydrochloric acid is 1.10^{-1} normal in hydrogen ions, the distilled water of our laboratory 1.10^{-5} normal to 1.10^{-6}, the purest water 1.10^{-7}, the tap water of our laboratory 1.10^{-8}, tenth normal sodium carbonate 1.10^{-12}, concentrated ammonia 1.10^{-14}. These determinations were made by the convenient system of indicators described by Ed. Salm [Z. physik. Chemie, **57**, 471-501 (1907); Chemical Abstracts, **1**, 684 (1907)].

the liquid. It is also noticed when a series of tests is made upon equal weights of a clay with different volumes of water. The sediment is most compact where the least water is used.

After reaching a dilution of 8000, the tubes were treated as follows:

Tube	A	B	C	D
Removed cc.	1	5	10	30
Added cc. 0.1 N NaOH.	0.1	1	5	10
Total volume, cc.	99	96	95	80

After shaking one hour and standing over night readings were made, then further additions and shakings were made several times. The results are in this table:

Additions of Tenth Normal Sodium Hydroxide to Hall Clay Co. Georgia Sagger Clay (Kaolin).

Tube		A			B				
cc. added	0	0.1	0.3	0.5	0.7	1	2	3	4
C.	81	80.5	....	....	....	....	....	....	....
N. C.	..	....	....	....	....	....	....	....	....
T.	..	....	78.5	5	2	1	1	Trace	1
D. T.	..	....	....	....	....	....	....	....	....
D.	..	....	....	84	92	88.5	91	93.5	93
S.	19	19.5	20.5	11	6	5.5	5	4.5	5

	C				D			
	5	7	8	10	10	15	20	30
	....	....	....	....	....	....	....	78
	....	....	....	....	....	....	....	....
	1	3	2	12	60	64	68	....
	....	....	74	64.5	....	....	....	....
	85.5	74.5	....	....	....	....	....	....
	8.5	19.5	22	23.5	20	21	22	22

[Throughout this paper the following abbreviations are used: C—clear, NC—nearly clear, T—Turbid (objects can still be detected through the liquid), DT—deeply turbid (objects can no longer be detected, but light is very evidently transmitted), D—dense (little, if any, light is transmitted), S—sediment.]

My interpretation of the above results is that the sodium displaces first any acid hydrogen in the gel (probably

nearly quantitatively), second that the sodium displaces calcium in the gel. The sodium compound so formed is soluble in water, and goes into suspension as the sodium sol of this clay. There is also in solution the displaced calcium and the excess of sodium hydroxide.

When a certain concentration of these is reached, the sodium colloid is salted out[6] of solution by these; which accounts for the larger bulk of sediment and the clarification of the solution with the larger additions.

The clay colloid molecule that thus goes into solution or suspension is probably quite complex, very likely a polymer[7] of variable size. The replacement of calcium by sodium is probably not complete, but variable, in accordance with the mass action law, and the molecule goes into suspension when there is a certain balance between the two elements.

While in ordinary solutions the forces that keep the molecules in solution far over-balance that of gravitation, they are probably only just sufficient in the case of the larger clay particles to retard the fall of the immense polymerized clay molecules; so that one sample of clay settles clear in 5 minutes, another in an hour, another in 24 hours, another in a month, or a year, and finally sufficiently large forces and small sizes are reached that the particles are in permanent solution. It is a boundary where solution and

[6] "Salting out" is a phrase employed in connection with the manufacture of soap. At one stage of the process the soap is very intimately mixed or dissolved in a considerable quantity of water. Addition of a suitable amount of common salt causes a separation into a layer of soap and a layer of salt water.

[7] A polymer is built up by the combination of two or more molecules of the same kind. As the observed osmotic pressures of colloidal solutions are always less than calculated for the total number of simple molecules present (J. Duclaux: J. chim. phys., 7, 405-46; Chemical Abstracts, 4, 405 (1910)), it is most probable that some of the molecules are polymerized; thus reducing the total number of molecular groups to what properly corresponds to the actual osmotic pressure. J. M. VanBemmelen [Z. anorg. Chem., 42, 300 (1904)] considers that alumina gel, in its successive stages of dehydration, exists as a series of hydrated polymers. A. Lottermoser [Z. angew. Chem., 22, 2417-2423 (1909)] considers that, under the influence of electrolytes, the single molecules assemble into molecular complexes, which last process may continue until we see visible precipitates in solutions.

suspension overlap or are identical. The clay colloid is very reactive, but only slightly soluble; hence its reactions are most noticeable in very dilute solutions.

In another experiment with the Hall Clay Co's Georgia Sagger Clay (Kaolin), it was attempted to have the hydrogen gel, or free acid colloid. Into each of four tubes was put 1 cc. strong hydrochloric acid, 97 cc. water, and 5 g. clay. These were shaken one hour, allowed to settle, decanted, and refilled, till the equivalent of a dilution 8000 times the first volume was reached. The liquid over the clay was brilliantly clear at all stages of dilution. Then additions of sodium hydroxide were made as in the preceding experiment, with results as follows:

Tube	G			H			
cc. 0.1 N NaOH.....	0	0.1	0.3	0.5	1	2	3
C	72.5	71	77	74	71	....	....
NC	....	....	....	....	..	....	....
T	....	....	....	....	..	1	1
DT	....	....	....	....	..	....	....
D	....	....	....	....	..	90.5	92
S	27.5	28	22	26	25	5.5	5

I			J						
5	7	8.5	10	15	20	30*	50*	75*	100*
..	..	....	..	..	..	..	..	..	85.5
..	..	....	..	..	..	..	..	..	....
1	1	1	1	1	2	20	51	81	....
..	..	....	..	..	..	64	27	..	....
89	91	92.5	73	78.5	88	..	..	..	....
5	5	5	6	5.5	?	16	23	21	17.5

This is interpreted as a removal in the form of chlorides of the bases that made coagulated gels, and a replacement by hydrogen, which also gives coagulated gels. Then the sodium hydrate reacted forming water and the sodium sol of the colloid:

$$\text{H gel} + \text{NaOH} = \text{H}_2\text{O} + \text{Na sol.}$$

When an excess of sodium hydroxide was used it reached such a degree of saturation of the water that the

* These additions were made with 2.5 n. NaOH. Therefore the volume was increased only one twenty-fifth the amount that would be due to — NaOH.

sodium sol could not longer remain in solution, but was coagulated or salted out.

The behavior of the untreated clay was almost the same as that of the water extracted clay.

These relations are more plainly shown in Fig. 2.

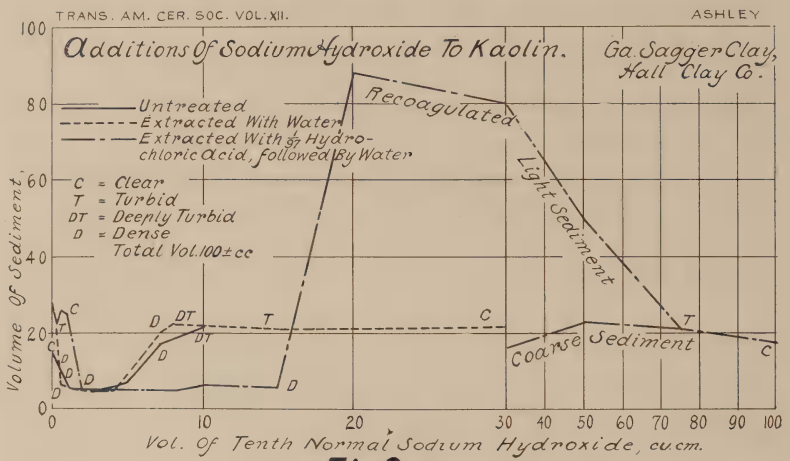


Fig. 2

The sodium does not displace calcium with the gel quantitatively, but partially, in accordance with the mass action law. If the calcium phase is partly removed, as with clays containing soluble salts by the repeated extractions with water, or wholly removed, as by extractions with hydrochloric acid and water, then the reaction will go further and a larger proportion of the sodium sol will be formed.

A similar investigation was made of the No. 1 light sagger clay of James P. Prall, Woodbridge, N. J. This clay closely resembles J. R. Cutter's No. 1 sagger clay and P. L. Ryan's No. 1 sagger clay, and behaves in many respects like Geo. Knowles & Sons' No. 12 English Ball Clay.

In this case the soluble salts were removed from the

clay by a dialysis lasting two months, in which the water was changed 33 times, a total volume of 16.625 liters being used. To prevent contamination with glass, the dialyser was coated with parafine, and the extract was concentrated in a block tin pan. (In the following analysis tin and lead were determined and deducted). The parchment paper used was treated for several days in the dialyser to remove soluble sulphates before introducing the clay. The extract was analyzed by Mr. A. J. Phillips, analytical chemist, in the Structural Materials Laboratory:

Dialysed Extract of Jas. P. Prall's No. 1 Sagger Clay.

Silica (SiO_2), per cent. of clay	0.091	50 grams sample
Alumina (Al_2O_3)	0.205	Started 09-3-22.
Ferric oxide (Fe_2O_3)	0.149	Stopped 09-5-15.
Lime (CaO)	0.085	33 changes of water.
Magnesia (MgO)	0.001	16.625 liters water used.
Sulphuric anhydride (SO_3)	0.174	
Sodium oxide	0.033	
Potassium oxide	0.039	
Organic	0.064	
Not determined (includes water, Cl, etc.)	1.033	
Total, dried at 110°	1.876	

The percentage of silica shown was puzzling. Our research laboratory is far from dust-free; but we had taken all precautions circumstances allowed to exclude it. Dr. Oswald Schreiner, who is well known for his excellent work on the subject of soil substances poisonous to vegetation, has assured the writer that in his dialyses, a portion of silica is invariably found in the extract. Suida[8] treated 250 kaolin with 1 g. ash free fuchsin, filtered, and obtained a filtrate of the following analysis: 3.18 SiO_2, 7.19 Al_2O_3, 38.56 CaO, 2.76 MgO, 44.42 SO_3, 2.76 Cl, Trace of Alkali. It seems positive that this clay contains a soluble silicate.

Qualitative tests by the writer gave on the fresh water extract of the sagger clay a strong, rather ruddy alkali

[8] Monatshefte d. Chemie, 25, 455 (1905).

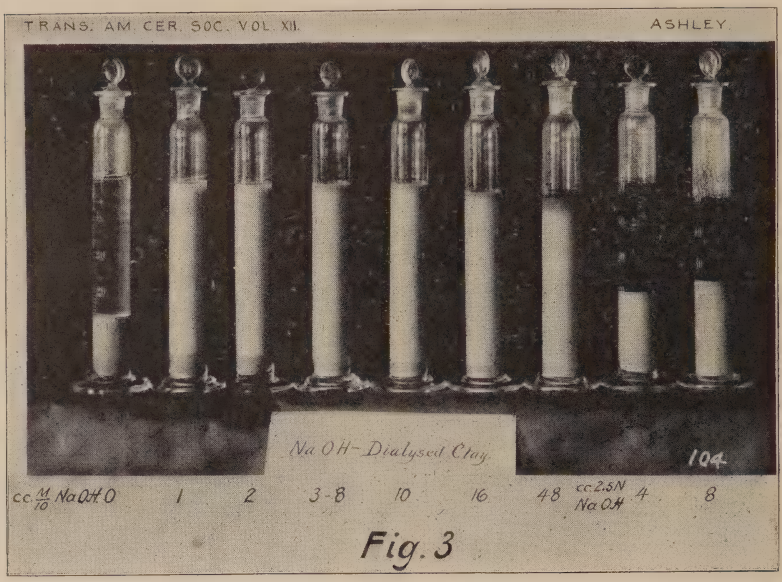
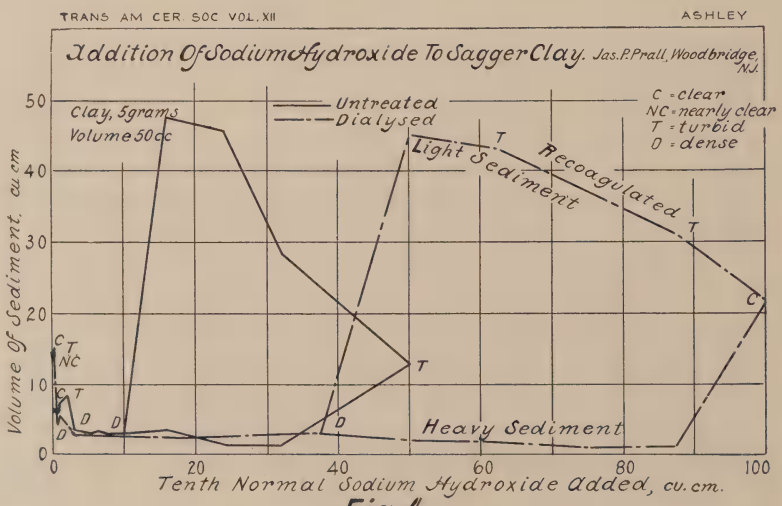

TRANS. AM. CER. SOC. VOL. XII.
ASHLEY
NaOH-Dialysed Clay.
104
cc. M/10 NaOH 0 1 2 3-8 10 16 48 cc. 2.5N NaOH 4 8

Fig. 3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Addition Of Sodium Hydroxide To Sagger Clay. Jas. P. Prall, Woodbridge, N.J.
Clay, 5grams
Volume 50cc
Untreated
Dialysed
C = clear
NC = nearly clear
T = turbid
D = dense
Light Sediment
Recoagulated
Heavy Sediment
Volume of Sediment, cu. cm
Tenth Normal Sodium Hydroxide Added, cu. cm.
0
10
20
30
40
50
60
80
100

Fig. 4

flame, no iron, a little alumina, quite a bit of CaO, a large amount of SO_3 and a trace of Cl; and in the hydrochloric acid extract, alkalies as above, both ferrous and ferric iron, a considerable NH_4OH precipitate evidently containing Al and Fe, two or three times as much CaO as above, and about the same SO_3 as above.

The effect of sodium hydroxide additions to the untreated clay and to the dialysed clay are shown by the photograph (Fig. 3), and a diagram (Fig. 4).

Unlike the Hall kaolin, the Prall sagger clay cannot be freed of soluble salts by repeated shaking with water, settling, and decantation; for, after a few portions of water are removed, a portion of the clay goes into very permanent suspension or solution. In other words, much of the colloid matter exists as alkali compounds which dissolve as soon as enough soluble salts are removed to give a sufficiently dilute water solution. This explains why the dialysed Prall clay was so much more readily affected than the untreated clay while the water extracted Hall clay gave very nearly the same results as untreated clay.

It was attempted to determine how much of this clay is removable by water extraction. Five grams of the clay were made up to a volume of 100 cc. in a graduated tube, shaken an hour, allowed to stand over night, about 90 cc. siphoned off and replaced by fresh water. This was repeated 62 times without any indication of approaching a clear extract.

The turbidity of each of these extractions was determined by shaking in a graduated Nessler tube. The tube was set upon a piece of newspaper, and the liquid at once drawn off by a cock near the bottom till the print could be read through the remaining liquid. The volume was read at this point. The results are given graphically in Fig. 5. [The necessity for shaking the extract before making the turbidity reading is shown by the following experiment. One gram Albert Lea Brick & Tile Co., Mich.,

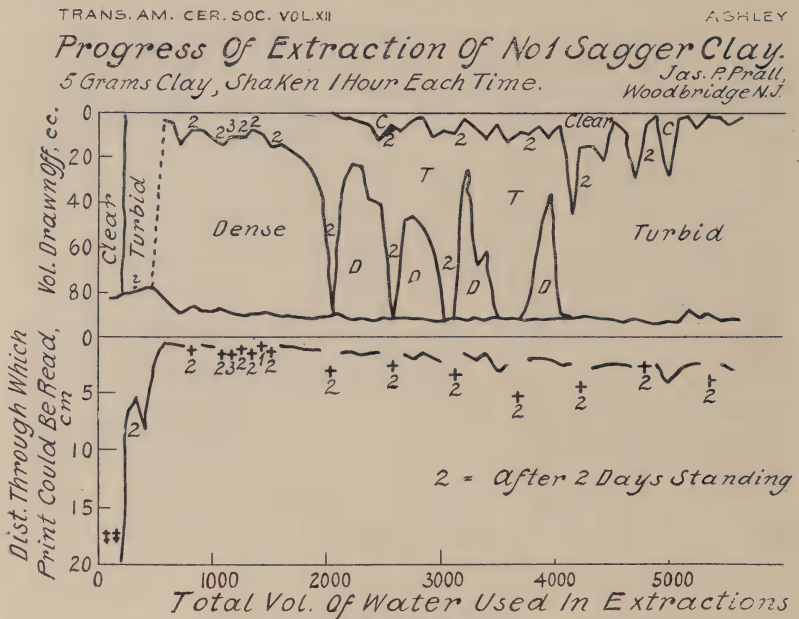
TRANS. AM. CER. SOC. VOL. XII
ASHLEY
Progress Of Extraction Of No 1 Sagger Clay.
5 Grams Clay, Shaken 1 Hour Each Time.
Jas. P. Prall, Woodbridge N.J.
Vol. Drawn Off, cc.
Clear
Turbid
Dense
Clear
Turbid
Dist. Through Which Print Could Be Read, cm
2 = after 2 Days Standing
Total Vol. Of Water Used In Extractions

Fig. 5

yellow clay was put into the tube with 11 cc 0.1 molar sodium oxalate, shaken and stood over night as usual. It was drawn off 5 cc. at a time, each portion diluted to 100 cc., and the turbidity of each portion measured as follows:

1st portion=portion between 90 and 85 cm. marks at the bottom	3.4 cm.
2d portion	3.7 cm.
3d portion	3.95 cm
4th portion	3.9 cm.
5th portion	4.05 cm.
6th portion	4.2 cm.
7th portion	4.0 cm.
8th portion	5.0 cm.
9th portion	5.1 cm.
10th portion	5.2 cm.
11th portion	6.2 cm.
12th portion	6.05 cm.
13th portion	6.85 cm.
14th portion	7.35 cm.
15th portion	8.6 cm.
16th portion	11.7 cm.
17 portion 10 to 5 cc.	17.25 cm.
18th portion mixed with 90 to 100 cc. portion.	

In a number of cases where apparently the liquid was of uniform density from top to bottom, turbidity measurements with liquid from different levels invariably showed

an increase from top to bottom.] Occasionally the tube on the shaker would be forgotten and allowed to stay on more than one hour. In such cases a higher turbidity was recorded. When the tube stood over two nights, as when a Sunday intervened, a lower result was obtained. At the time of stopping the test 3.5 grams clay remained in the tube.

Since the highest turbidities were obtained in the earlier extractions or in the later with longer shaking, it is evident that the water in these later cases was far from saturated. Why solution should be so rapid in the early part of the experiment and so slow in the latter part is an interesting subject of speculation. I am inclined to think that alkaline silicates in the clay, such as feldspar and mica, were being gradually converted from crystalline compounds to soluble colloids, and were the source of the steady daily supply.

These results agree with the figures given by Parmelee[9] last year for the additional amount of clay removed with each extraction when using the centrifugal apparatus for mechanical analysis.

Another experiment will illustrate the remarkable solvent power of water for fine grained minerals. The X Wad Clay of the Johnson-Porter Clay Co., when elutriated in the Schultze apparatus, gives a very considerable residue in each of the three cans, and this residue appears to consist almost entirely of round grains of silica. Now as the viscosity of water decreases rapidly with increased temperature, it seemed that the carrying capacity of the water current should fall off with increased temperature, and larger residues should be left in the cans; also that this wad clay is especially suited to test the principle because of its large residues. The apparatus was set up as shown in Fig. 6, except that no thermostat was used to control the temperatures. Ordinary tap water was used which had passed through the Pittsburg city filtration plant and

[9] Trans. Am. Ceramic Soc., 11, 479, 480 (1909).

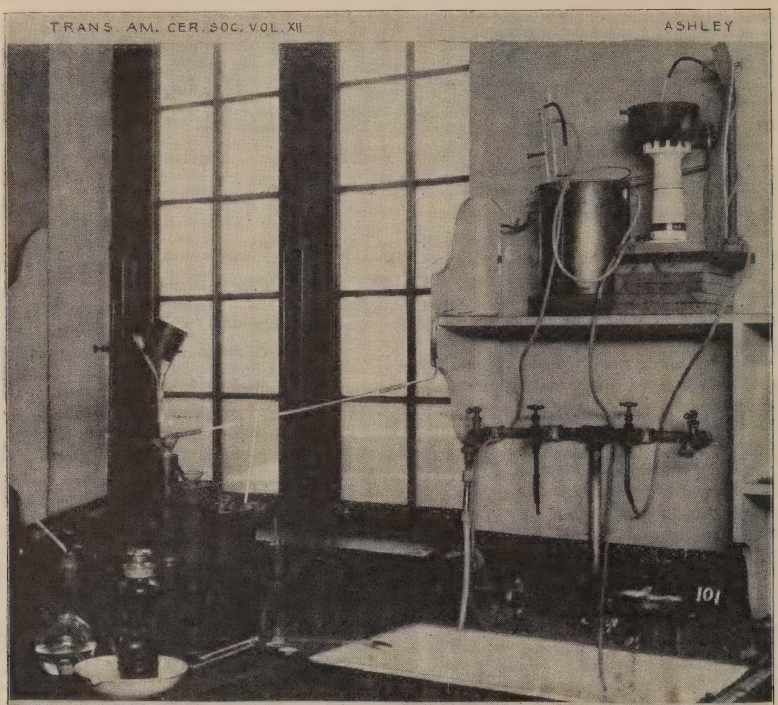

Fig. 6

had a hydrogen ion concentration of 1.10^{-8}. The results are platted in Fig. 7. The expected result was attained only in the first can. In the second and third cans the amount of residue fell off almost proportionately to the rise in temperature (except at 40° in the third can).

The only explanation that seems plausible is solution. That 20 per cent less residue was obtained in the second can should not be taken as meaning that 20 per cent was dissolved, but that 20 per cent had its size so much reduced by solution from its surface that it became small enough to pass over into the third can. Also particles in the third can became reduced in size, and then passed into the over-

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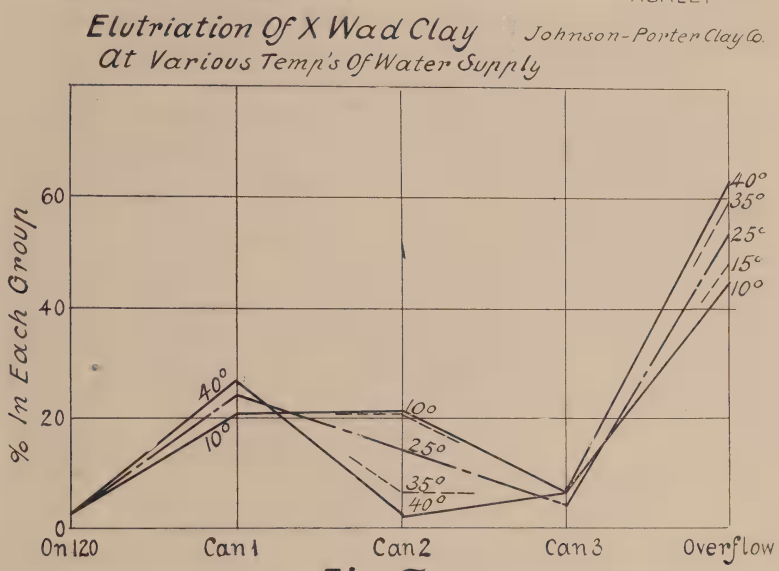

Fig. 7

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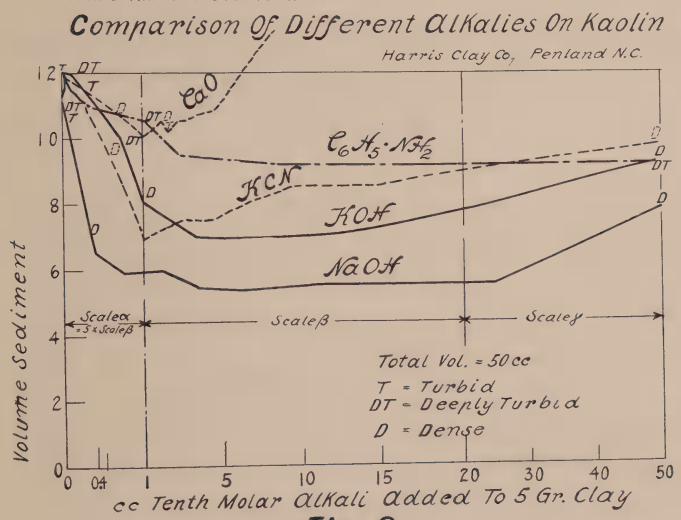


Fig. 8

flow. These experiments on the solvent effect of water in mechanical analysis are to be carried further with special apparatus in the coming year.

Ammonia (NH_4OH), Potassium hydroxide (KOH), and Aniline give similar results to sodium hydroxide (NaOH), (Fig. 8). Glycerine ($C_3H_5(OH)_3$) appears to be without effect.

Besides using hydrochloric acid and water extraction to remove those bases that conserve coagulation, the natural chemical idea is to remove them by a simple chemical reaction, a double decomposition, e. g., sodium carbonate is much used in the casting process. Its action on the calcium gel would be

$$Na_2CO_3 + Ca\ gel = CaCO_3 + Na_2\ sol.$$

and on the soluble calcium salts

$$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4$$

Calcium carbonate in both cases is insoluble and so removed from action. As other experiments show Na_2SO_4 to be a pretty vigorous salting-out reagent, the solvent action of sodium carbonate is mainly upon the colloid itself, though secondarily upon soluble salts. Any other alkaline salt whose acid ion gives an insoluble precipitate with bivalent and trivalent bases may be used to deflocculate clays by removing such bases; the following have been used in these experiments:

Sodium oxalate, $Na_2C_2O_4$.
Potassium oxalate, $K_2C_2O_4$.
Ammonium oxalate, $(NH_4)_2C_2O_4$.
Sodium silicate, approx., Na_2 0.3 SiO_2.
Soft soap.
Borax, $Na_2O:2\,B_2O_3$.
Potassium phosphate, K_3PO_4.
Sodium phosphate, Na_3PO_4.
Di-sodium hydrogen phosphate, Na_2HPO_4.
Sodium di-hydrogen phosphate, NaH_2PO_4.
Sodium hydrogen ammonium phosphate, $NaHNH_4PO_4$.
Potassium syanide, KCN.
Potassium ferrocyanide, $K_4FeC_6N_6$.
Sodium arsenite, $NaAsO_2$.
Sodium sulphide, Na_2S.
Potassium permanganate, $KMnO_4$.
Also many dyes.

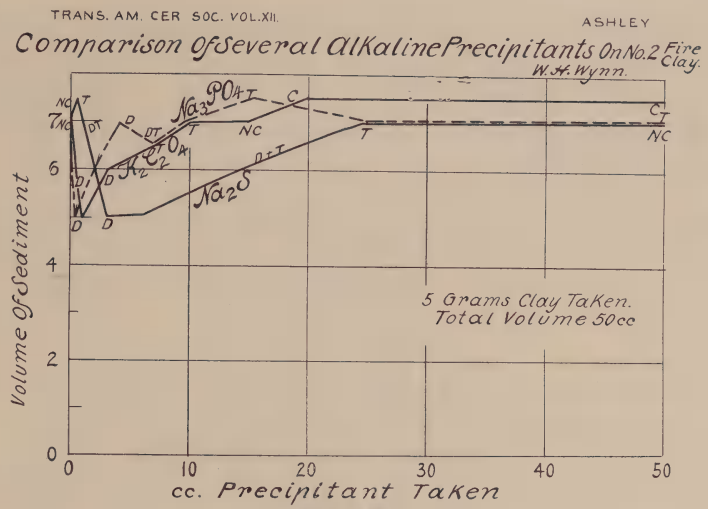
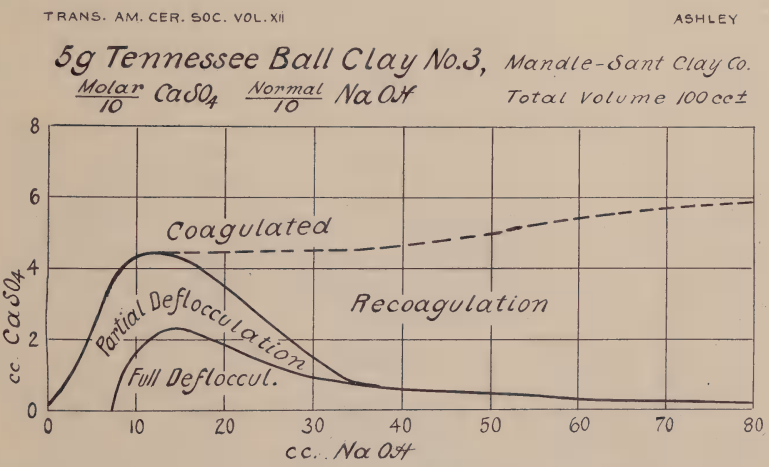

TRANS. AM. CER SOC. VOL. XII.
ASHLEY
Comparison of Several Alkaline Precipitants On No. 2 Fire Clay.
W. H. Wynn.
Volume of Sediment
cc. Precipitant Taken
5 Grams Clay Taken.
Total Volume 50cc
Na2PO4
Na2S
0
2
4
6
10
20
30
40
50

Fig. 9


TRANS. AM. CER. SOC. VOL. XII
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5g Tennessee Ball Clay No. 3, Mandle-Sant Clay Co.
Molar/10 CaSO4 Normal/10 NaOH
Total Volume 100cc±
cc CaSO4
cc. NaOH
Coagulated
Recoagulation
Partial Deflocculation
Full Deflocculation
0
2
4
6
8
10
20
30
40
50
60
70
80

Fig. 10

Sodium carbonate is not necessarily the most effective of the group with a given clay, though it is the most used industrially. The behavior of No. 2 fireclay toward potassium oxalate, tri-sodium phosphate, and sodium sulphide is shown in Fig. 9.

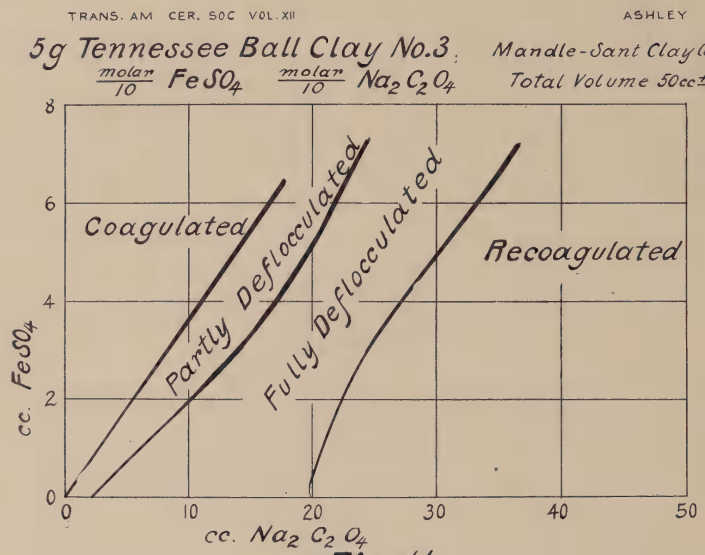

Fig. 11

To illustrate the difference between the mass action solvent effect of alkaline hydroxides and the quantitative effects of alkaline precipitants, diagrams are given showing the effect of sodium hydroxide in combatting additions of calcium sulphate to the Tennessee Ball Clay No. 3 of the Mandle-Sant Clay Co., (Fig. 10), and of sodium oxalate in neutralizing additions of ferrous sulphate to the same clay (Fig. 11).

Compounds containing divalent elements are in general precipitants, but a few exceptions are noted.

Barium carbonate, within narrow limits is an energetic deflocculating agent. Its effect is apparently to stop

the effect of calcium sulphate by completely precipitating it from solution:

$$BaCO_3+CaSO_4=BaSO_4+CaCO_3$$

Both the products of the reaction are very insoluble.[10]

Lead acetate might be expected to give a similar reaction, but failed when tried with Prall sagger clay.

Barium hydroxide has a similar action. The equations may be:

$$BaO_2H_2+CaSO_4=BaSO_4+CaO_2H_2$$
$$CaO_2H_2+CO_2=CaCO_3+H_2O$$

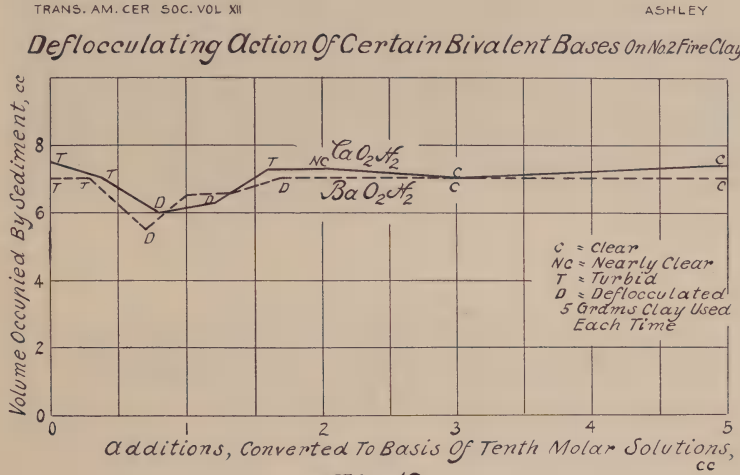
TRANS. AM. CER SOC. VOL XII
ASHLEY
Deflocculating Action Of Certain Bivalent Bases On No2 Fire Clay
Volume Occupied By Sediment, cc
Additions, Converted To Basis Of Tenth Molar Solutions, cc
Ca O2 H2
Ba O2 H2
C = Clear
NC = Nearly Clear
T = Turbid
D = Deflocculated
5 Grams Clay Used Each Time

Fig. 12

It seems more likely, however, that the action is on the iron sulphates or alkali sulphates:

$$BaO_2H_2+FeSO_4=FeO_2H_2+BaSO_4$$
$$BaO_2H_2+Na_2SO_4=2\,NaOH+BaSO_4$$

Ferrous hydroxide would be insoluble, and sodium hydroxide is a powerful deflocculating agent.

[10] To prevent loss of plasticity through use of barium carbonate, apparently an excess should be used to keep the gels coagulated. This explains the direction of one authority to use twice the theoretical amount.

Calcium hydroxide in a few cases acts as a deflocculant. The reaction is likely upon alkaline salts with formation of a less soluble calcium compound, e. g.:

$$CaO_2H_2 + Na_2SO_4 = CaSO_4 + 2\,NaOH$$

The following tables give the data obtained with barium hydroxide and with calcium hydroxide upon No. 2 fireclay. See also Fig. 12.

Action of Tenth Molar Barium Hydroxide upon 5 g. No. 2 Fireclay from W. H. Wynn, Decatur, Pa.

cc. $Ba(OH)_2$	0	0.3	0.7	1	1.3
Clear	..	..	..	..	..
Turbid	43	43	7	7	10
Dense	..	..	37.5	36.5	33.5
Sediment	7	7	5.5	6.5	6.5
H ion concentration	1.10^{-5}	1.10^{-5}	1.10^{-7}	1.10^{-9}	1.10^{-10}
	1.7	3	7	15	30
	..	43	43	43	43
	13	..	..	..	..
	30	..	..	..	..
	7	7	7	7	7
	1.10^{-10}	1.10^{-10}			

Action of Tenth Molar* Calcium Hydroxide upon 5 g. No. 2 Fireclay from W. H. Wynn, Decatur, Pa.

cc. $Ca(OH)_2$	0	0.4	0.8	1.2	1.6	2
Clear	..	..	..	..	..	..
Turbid	92.5	93	14	16	92.7	92.7
Dense	..	..	80	77.7	..	..
Sediment	7.5	7	6	6.3	7.3	7.3
H ion concentration	1.10^{-5}	1.10^{-5}	1.10^{-7}	1.10^{-9}	1.10^{-10}	1.10^{-11}
	3	5	8	10		
	93	92.6	92.5	92.7		
	..	..	..	..		
	..	..	..	..		
	7	7.4	7.5	7.3		
	1.10^{-11}	1.10^{-11}	1.10^{-12}	1.10^{-13}		

On first mixing this series of tubes, that with 0.4 lime showed a dense suspension. On shaking again by hand just before placing in the shaking machine, 0.4 and 0.8

* Owing to the impossibility of preparing tenth molar calcium hydroxide, the equivalent amount of fiftieth molar solution was used.

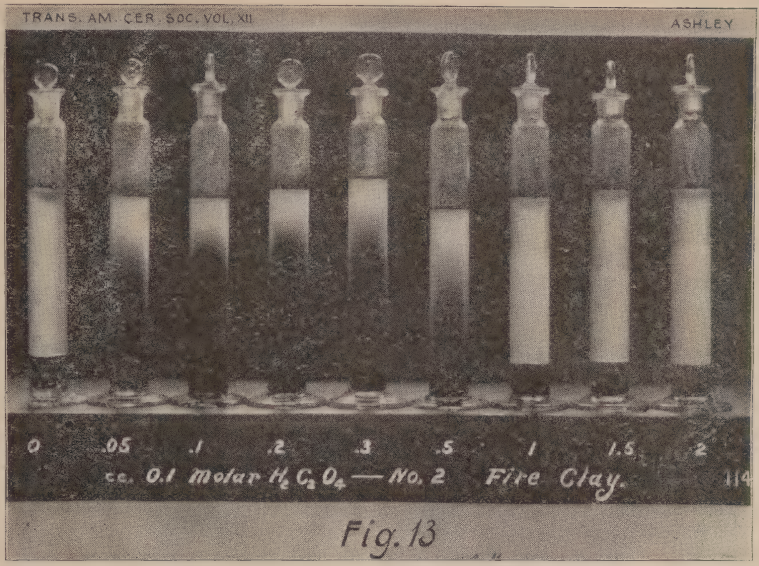
TRANS. AM. CER. SOC. VOL. XII
ASHLEY
0 .05 .1 .2 .3 .5 1 1.5 2
cc. 0.1 Molar $H_2C_2O_4$ — No. 2 Fire Clay.

Fig. 13

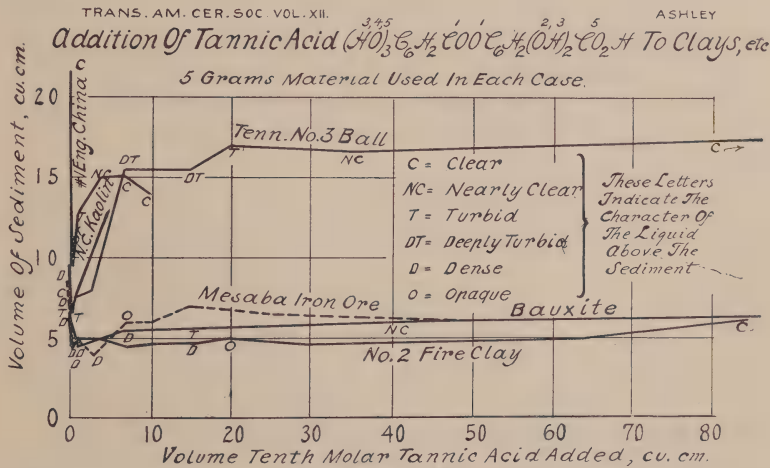
TRANS. AM. CER. SOC. VOL. XII.
ASHLEY
Addition Of Tannic Acid $(HO)_3^{3,4,5}C_6H_2^{1}CO^{1}OC_6H_2^{2,3}(OH)_2^{5}CO_2H$ To Clays, etc
5 Grams Material Used In Each Case.
Volume Of Sediment, cu. cm.
Volume Tenth Molar Tannic Acid Added, cu. cm.
Tenn. No. 3 Ball
#1 Eng. China
N.C. Kaolin
Mesaba Iron Ore
Bauxite
No. 2 Fire Clay
C = Clear
NC = Nearly Clear
T = Turbid
DT = Deeply Turbid
D = Dense
O = Opaque
These Letters Indicate The Character Of The Liquid Above The Sediment

Fig. 14

showed dense suspension. After an hour on the machine, the dense suspension had shifted to 0.8 and 1.2. In other words, only a portion of the colloid clay was acted upon when first mixed, and 0.4 cc. lime was sufficient to put it in suspension. When with further shaking, more of the colloid clay was exposed to the action of the lime, a proportionately larger amount of lime was required to effect suspension. This behavior was frequently observed with other reagents and clays.

Even oxalic acid acts as a deflocculant (Fig. 13). The action is most likely upon a calcium salt of a weak colloidal acid.

Tannic acid appears to exert its deflocculant effect by taking into solution iron (or possibly aluminum) from colloid gels. It appears to be without action on clays not containing iron or aluminum, and deflocculates and is strongly colored by clays containing iron (Fig. 14). In the case of W. H. Wynn No. 1 Fireclay the iron of the clay was wholly insoluble in water, but soluble in the tannic acid.

While the most probable cause of the deflocculating action of oxalic acid and of tannic acid is the removal of coagulating bases, yet that would leave equivalent amounts of hydrogen with the colloid matter. It seems likely then that certain free colloid acids within very narrow ranges are soluble in water.

Whitney and Straw (J. Am. Chem. Soc., 29, 328, 1907), found colloidal silver to have a maximum of suspension with no addition and a second maximum in 0.004 normal sodium hydroxide solution. Their second maximum corresponds to the sodium sols we have discussed, but the first is evidently something different. It might possibly be a free acid sol, but the question is an open one. I have not yet observed 2 maxima in any clay series.

Franz Hundeshagen (Z. angew Chem., 21, 2455, 1908), considers that a portion of the hydrogen of kaolin is

strongly acid in character while the remainder is weakly basic.

T. B. Wood and W. B. Hardy (Proc. Roy. Soc., London (B), 81, 31-43, 1909; Chemical Abstracts 3, 1539 1909), state that the protein molecule contains H and OH. Proteins, therefore, as a class are amphoteric electrolytes. They react with acids and alkalies to form salts, but the reactions are not precise, an indefinite number of salts being formed. A small amount of either acid or alkali causes hydrosol formation to reach a maximum, excess reprecipitates. They show curves for gluten similar to Fig. 10 of this paper.

Hundeshagen is then supported by this analogy from organic chemistry, and certain acids may be expected to have a limited deflocculating power on clays.

The following reagents in these experiments acted invariably to coagulate the clays tested.

Calcium chloride, $CaCl_2$	Carbonic acid, H_2CO_3
Ammonium nitrate, NH_4NO_3	Potassium dichromate, K_2CrO_4
Sodium sulphate, Na_2SO_4	Sodium acetate, $NaC_2H_3O_2$
Ammonium sulphate, $(NH_4)_2SO_4$	Hydrochloric acid, HCl
Magnesium sulphate, $MgSO_4$	Ammonium chloride, NH_4Cl
Calcium sulphate, $CaSO_4$	Sodium chloride, $NaCl$
Ferrous sulphate, $FeSO_4$	Zinc chloride, $ZnCl_2$
Ferric Sulphate, $Fe_2(SO_4)_3$	Magnesium chloride, $MgCl_2$
Lead acetate, $Pb(C_2H_3O_2)_2$	Barium chloride, $BaCl_2$

There was used as wide a range of clays as possible in this investigation: English and American kaolins and ball clays, brick surface clays, sagger clays, peat and highly organic surface clays, joint clays, shales, slate, No. 1 and No. 2 fireclays, and fullers' earth. The slate was least affected, shale next, and No. 1 fireclay next. The others were readily acted on.

The writer has also deflocculated by the reagents described potter's "flint" (quartz), feldspar, mica, bauxite (not completely), iron ore, and peat (not completely). Pure water seems to give the maximum effect with the

potter's "flint" (ground sandrock), potash, feldspar, and soda feldspar.

Martin Boettcher[11] has used ammonia, lithium hydroxide, calcium hydroxide, sodium hydroxide, potassium hydroxide, sodium carbonate, lithium carbonate, and potassium carbonate to deflocculate a stoneware body. He made casting slips, determined their viscosity by an efflux viscosimeter, with two mm. orifice, and then diluted a portion of his slip in test tubes, obtaining series much like those described here. He found a minimum of viscosity of the thick slip to coincide with a maximum of suspension of the diluted slip in the test tubes. This observation is of value in showing that the effect of the reagent depends mainly on its ratio to the clay, rather than upon its concentration in the liquid medium.

Boettcher was puzzled to find an explanation for a phenomenon which he called super-stiffening. This action is easily accounted for on the hypothesis that under the conditions of his work, the chemical reaction had not proceeded to completion at the time of his viscosity measurements. Thus, a re-determination of viscosity some time later would find the tests with the larger amounts of reagent more fluid than at the time of the first measurement.

Boettcher noted that deflocculation occurs within narrower limits when a larger amount of calcium sulphate is in the clay.

F. Foerster[12] had previously noted that 0.1 per cent gypsum hindered the action of alkali on casting clip; but that the hindrance could be overcome by adding reagents to precipitate the lime, such as sodium carbonate (Na_2CO_3) or a mixture of di sodium-phosphate and sodium hydroxide, ($Na_2HPO_4 + NaOH$).

Boettcher found lithium carbonate, sodium hydroxide, and ammonia to effect the suspension of animal charcoal similarly to clays.

[11] Sprechsaal, 42, 117-9, 133-5, 153-5, 168-70, 186-7, 199-201, 217-9, 233-5, 252-3 (1909).

[12] Die chemische Industrie, 28, 733-740 (Dec. 15, 1905).

"According to Hopkins,[13] when soils are extracted with a solution of sodium chloride, the organic soil acids react with the sodium chloride to produce free hydrochloric acid. This reaction is quantitative, and the free acid can be titrated, and is equivalent to the original amount of acid present in the soil."

Morse and Curry[14] quote Hopkins as above, but appear rather cautious as to accepting his views. They make such conclusions as the following:

"4. Clays and soils react with potassium, sodium, and ammonia in equivalent quantities when these bases are present as salts. Calcium, magnesium, iron, and aluminum constitute the largest amount of reacting bases." (i. e., bases removed from the clay by the alkaline salts).

"9. The acid character of the solutions formed in these ways does not demand the presence of an acid to complete an explanation for their formation." (To the present writer, the careful analytical work of Morse and Curry seems to indicate exactly the opposite to their conclusion.)

"17. In a general way the tendency for clay soils, etc., is to reduce the solubility of bases with which they come in contact."

Their observation that, "We have already seen how like an acid the clay behaves towards carbonates" seems opposed to their conclusions.

Nichols[15] has observed the rate of settling of slimes in graduated tubes, and the effect of lime and sulphuric acid in hastening the settement. He found increased temperature to accelerate the sedimentation in proportion to the rate at which it diminishes the viscosity of water.

Buxton and Rohe[16] found that temperature has little effect on the adsorption of dye by inorganic colloids, but

[13] U. S. Dept. Agri., Bur. Chem., Bull. 73, p. 14.

[14] 19th and 20th reports of the New Hampshire Agricultural Experiment Station, pp. 262-310 (Nov. 1, 1908).

[15] Mining and Scientific Press, (1909).

[16] Beit. Chem. Physiol. (Hofmeister), 11, 479-501; Chemical Abstracts, 3, 505 (1909).

Weber[17] found that when adding deflocculating agents, "with certain clays the application of heat is very serviceable, whilst with others, that is, those which contain much colloidal silicic acid, heat acts in the converse way and gelatinizes the colloids."

APPLICATIONS.

Determination of Soluble Salts.

The principal difficulty in soluble salt determinations has been to know when to stop. After such common salts as calcium, magnesium, and sodium sulphates and sodium chloride have been removed by successive extractions with cold water, then without a break (or rather with decided overlapping) alkaline silicates are removed. While some of the alkaline silicates so removed are derived from the colloid portion of the clay, there seems to be a tendency for the crystal portion of the clay to go over to the colloid form, at least to such an extent as to give each crystal a colloid film as coating.

When hot water is used in extracting the soluble salts, the tendency to break down the crystal silicates is increased.

When extractions are made with a solution of sodium chloride or potassim nitrate, the gels are decomposed, e. g.:

$$2\ NaCl + Ca\ gel = Na_2\ gel\ or\ sol + Ca\ Cl_2$$

also even such insoluble substances as calcium phosphate are subject to decomposition by salt solutions. Hence extractions by salt solutions are liable to give much more than the true water soluble bases of a soil.

Schreiner and Failyer[18] remark that dried soils give up their soluble salts in somewhat greater concentration than fresh damp soils.

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[17] Trans. Eng. Ceramic Soc., 8, [Part I], 14 (1909).
[18] U. S. Dept. Agr., Bur. Soils, Bull. 31, p. 11.

Bleininger, in his investigation on destroying excessive plasticity by preheating clays, noted that heating the clays to 250 to 300° C. seems greatly to facilitate movement of the soluble salts through the pores of the clay. These temperatures are necessary to drive off the hygroscopic water of the clays.

Ries[19] even found soft burning of Wisconsin clays to cause them to yield much more soluble salts than the crude clays. Hard burned clays yielded less than soft burned.

The following method of soluble salt determination is proposed as worthy of study:

Take 100 grams of air dry clay, heat at 300° C. for one hour, and weigh. The loss equals hygroscopic moisture. Crush to pass a 60 mesh sieve; put into a vessel containing one liter of water; shake one hour; let settle over night. Siphon or decant off a definite volume, even if turbid. Add from a burette a measured portion of magnesium sulphate just sufficient, or a little in excess, to coagulate the clay sol. In aliquot portions of the resulting clear liquid the various determinations are to be made by usual quantitative methods. The silica present may necessitate an evaporation to dryness with hydrochloric or nitric acid. Organic compounds may require special treatment or ignition. From the total sulphuric anhydride found is to be subtracted that added as magnesium sulphate. If we assume that no magnesium was present as a soluble salt, which is nearly the case in the presence of a turbid solution, we may assume that the magnesium added as sulphate minus the magnesium found equals the magnesium used in coagulating the clay; also that from the alkali found is to be deducted an amount equivalent to the magnesium used in coagulating the clay. The action of the magnesium sulphate may be expressed by the following equation:

$$MgSO_4 + Na_2 \text{ with sol} = Mg \text{ with gel} + Na_2SO_4$$

Solutions of calcium sulphate, calcium chloride, or

[19] Clays of Wisconsin; Wisconsin Survey, Bull. 15, 22 (1906).

magnesium chloride, bivalent bases with simple acids, might be used equally well, save that sixtieth molar is about as concentrated as the calcium sulphate can be prepared, as it has a tendency to crystallize out on standing.

Use of Barium Carbonate to Prevent Scum.

The difficulty in some methods for the determination of the amount of barium carbonate required to neutralize the soluble sulphates in clays is that barium carbonate reacts not only with the soluble sulphate (equations 1 and 2) but also with the clay colloids, as in equations 3 and 4:

$$BaCO_3 + CaSO_4 = BaSO_4 + CaCO_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$
$$BaCO_3 + NaSO_4 = BaSO_4 + Na_2CO_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$
$$BaCO_3 + Na_2 \text{ with sol or gel} = Ba \text{ gel} + Na_2CO_3 \ldots\ldots (3)$$
$$BaCO_3 + H_2 \text{ with gel} = Ba \text{ gel} + H_2CO_3 \quad \ldots\ldots\ldots\ldots (4)$$
$$Na_2CO_3 + Ca \text{ gel} = Na_2 \text{ sol} + CaCO_3 \quad \ldots\ldots\ldots\ldots\ldots (5)$$

There is reason to believe that the action of barium carbonate is first upon the soluble sulphate and second upon the colloids, since Dutoit and Duboux[20] have shown this to be the case with wines.

If the amount of sulphuric anhydride in the clay has been accurately determined, it would seem that the theoretically equivalent amount of barium carbonate might be added. If the clay were worked sufficiently after the addition of barium carbonate, it is conceivable that the reaction between the slightly soluble barium carbonate and the sulphates would be nearly complete. That this is unlikely to occur in practice is probably the reason for the direction given by Seger[21] to use twice the theoretical quantity. Another reason hitherto unrecognized is that equation (2) above forms alkaline carbonates. These tend to form the clay sol (equation 5), and thus lessen the plasticity. But if an excess of barium carbonate is used, it

[20] Schweiz. Wochschr., 46, 672-8; Chemical Abstracts, 3, 469-70 (1909).

[21] Handbuch der gesammten Thonwaarenindustrie, von Bruno Kerl. Dritte Auflage, bearbeitet von Eduard Cramer und Dr. Hermann Hecht (1907), page 523.

will restore the gel, (equation 3), and thus preserve the plasticity.

The "practical" test for the barium carbonate requirement of a clay, consisting in adding to equal weights of clay a series of increasing weights of barium carbonate, shaking with water, and finding which members of the series completely precipitate all the barium added, is liable to lead to wasteful use of barium carbonate to combine with the harmless colloids of the clay.

Hirsch[22] made an excellent study of this test. While he did not understand the cause of the excessive taking up of barium, he found a means of combatting it. He directed that 4 grams of aluminum chloride be used in the test with 100 grams of clay, and that the test with barium would then be "faultless." The action of the aluminum chloride is to combine with the colloids:

$$AlCl_3 + R \text{ with colloid} = Al \text{ gel} + RCl_3$$

Barium probably has little or no action on aluminum gel, and so acts on the soluble sulphates only.

Mechanical Analysis.

The data obtained make possible a criticism of present methods of preparing clays for mechanical analysis, and of the conduct of the mechanical analysis.

Shaking with cold distilled water in sufficient quantity will perfectly deflocculate the clay if all the colloid matter is in the form of alkaline compounds, otherwise not. If more water is used than the quantity that just suffices, the crystal matter will be attacked, and tend also to go over to the colloid form. If hot water or grinding is used, the above actions will be accelerated. If hard water is used, it will tend to keep the colloid matter coagulated on the crystal grains.

[22] Tonindustrie-Zeitung, 28, 491 (1904).
[23] Comptes rendus, 136, 1629 (1903); 137, 369.

The method of Schloessing[23] is the most general and correct of methods in use. He extracts the clay with a portion of nitric or hydrochloric acid, and then washes till the filtrate is no longer acid. This removes the soluble salts and most of the basic ions of the gels. He then treats with ammonia. This forms the ammonia sol of the colloids, and leaves the crystals bare.

The United States Department of Agriculture, Bureau of Soils[24] takes 5 grams clay, 75 cc. water and 10 drops strong ammonia, and shakes violently for 6 hours. The shaking is much in excess of what would be required with a proper choice and manipulation of solvents. The ammonia is found by them to be useless on soils containing carbonates, and is omitted with such soils. Its action in such cases is to assist in salting out the colloids rather than to assist in dissolving them. Ammonia will be found most effective with acid soils low in soluble salt content. It forms the ammonia sol from these, and thus uncovers the grains; except as prevented by the salting out effect of the soluble salts present, or by excess of the reagent.

The Tonindustrie Kalender recommends 1 cc. sodium hydroxide solution (strength ?) to 40 grams of clay. This is a more vigorous reagent than ammonia, and so can overcome more soluble salts. On the other hand, if the clay is alkaline, it will assist the more vigorously in salting out the colloids, and so preventing deflocculation.

In general, alkalies are efficient for removing the colloid coating from the grains, when, 1st, the clay is not already alkaline, 2nd, soluble salts are low, 3rd, the colloid is not combined with polyvalent bases, such as calcium, magnesium, iron, and alumina, 4th, just the right amount of alkali is used, as determined by tube experiments.

It is exceedingly important that a *slight excess* of alkali shall not be added.

In Fig. 3, which shows the effect of sodium hydroxide

[24] Bureau of Soils, Bull. 24, 920 (1904).

on New Jersey sagger clay of Jas. P. Prall, it will be noticed that 3 cc. tenth normal sodium hydroxide reduce the sediment to 3 cc. This sediment presents a clean, wholly granular appearance. The sol in the tube above the sediment has reached its maximum density. Up to 37.5 cc. may be added without producing any further change in appearance. Then 50 cc. starts to salt out the gel. A gradual stiffening of the gel seems to set in and its volume simultaneously to diminish with further additions. Owing to this stiffening it has increasing carrying power. As it takes up first the finest part of the sediment, then the coarser portions, the sediment appears to diminish, to become less distinct, and finally to become identical with the coagulated gel. Obviously while the colloid matter is in shape to buoy up the granular matter of the clay it is in a very unsuitable condition for the mechanical analysis.

I do not know that anyone has used alkaline precipitants to deflocculate clays for mechanical analysis, but I find them very efficient where the gel is combined with polyvalent bases or the soluble salts contain polyvalent bases. I have used sodium oxalate mostly, but potassium and ammonium oxalate seem nearly as vigorous. In special cases other reagents might be especially adapted to remove the bases present. Any reagent giving perfect deflocculation should be satisfactory.

The two general methods of mechanical analysis are sedimentation and elutriation. The principal difference between the two is that the former is intermittent, while the latter is continuous and may employ a much larger volume of water.

It has been shown in the experimental part of this paper that water has a profound solvent effect upon silica grains, and, presumably, upon other minerals, and that this effect is greater the higher the temperature. Hence, it is desirable that the water used in mechanical analysis be kept at a low standard temperature, say 0° C., and that the volume be kept as low as possible. This last considera-

tion is a strong argument for discarding elutriation methods and adopting sedimentation. It seems probable that instead of running elutriations until the overflow is clear, they should be run for a definite length of time. This will soon be tried out.

When, owing to the great volume required, ordinary tap water is used in elutriation, there is liability that the bases in it will undo the work of the deflocculating agent. I have had this happen when sodium oxalate had been used with the clay.

To get around the difficulty, the bulk of the sol can be removed by sedimentation and decantation four times repeated, using distilled water and removing 0.9 of the liquid each time; then elutriation of the granular residue with tap water. In such a case, where 30 minutes was allowed for each sedimentation, it was found that .3 per cent crystalline matter was lost that ought to have remained in the third can. A longer time should be allowed.

Another difficulty noticed in elutriation with metal cans is a tendency for fine clay that should overflow to lodge on the conical bottom and the vertical sides. This is an electrolytic phenomenon which accompanies corrosion of the metal can. It was evidently observed by Parmelee and Moore[25] in their comparative study of methods of mechanical analysis; for in one of their experiments, they had the inside of the cans varnished.

Sedimentation methods include those where gravitation is the force causing the grains to collect at the bottom of the vessel, and those where centrifugal force causes a much more rapid collection. Owing to the packing action of the centrifugal machine, the liquid overlying the grains is easily decanted, while a disturbance of the loose lying grains in a sedimentation experiment is best avoided by siphoning off the water.

Sedimentation methods require a skilled operator

[25] Trans., 11, 477 (1909).

and frequent standardization of sizes of grain. It is desirable to study whether slightly alkaline water will give better results than pure water in making the successive changes, also whether there is a limit to the number of changes of water that should be employed (to minimize the solvent effect upon crystal grains).

Casting Process.

Hitherto the choice of deflocculents for the casting process has been almost wholly empirical. Weber,[26] whose patented casting process of glass pots and other refractories is used in more than 20 factories, after describing the use of alkalies, the soda salts of carbonic acid, phosphoric acid, oxalic acid, boracic acid, barium hydroxide, and calcium hydroxide, says: "Which of the above named alkalies should be used, and the quantity, must be found out for each clay separately according to its position."

Foerster[27] noticed that calcium sulphate hindered the action of alkalies in preparing clays for casting, and that its effect could be set aside by the use of a precipitant for lime, as sodium carbonate.

The methods given in this paper make it possible to determine, first, what amounts of soluble salts are in the clay; second, what bases are combined with the gel; third, what reagents are best suited chemically to react with these and dissolve the colloid matter of the clay.

Fig. 15 illustrates the separate and joint action of sodium carbonate and sodium silicate on a ball clay and a china clay and a body made from them. The proportions used in ordinary work while variable, and determined by tradition or experiment, are about one-tenth of a per cent. of each. The lower right hand figure shows that the deflocculation is not complete at this per cent. While Boettcher says that he successfully cast a stoneware clay with

[26] Trans. Eng. Ceramic Society, 8, [1], 16 (1909).
[27] Die chemische Industrie, 28, 733-40 (1905).

the proportion of sodium hydroxide giving maximum deflocculation, it should be determined practically whether this point or some point short of it gives best results.

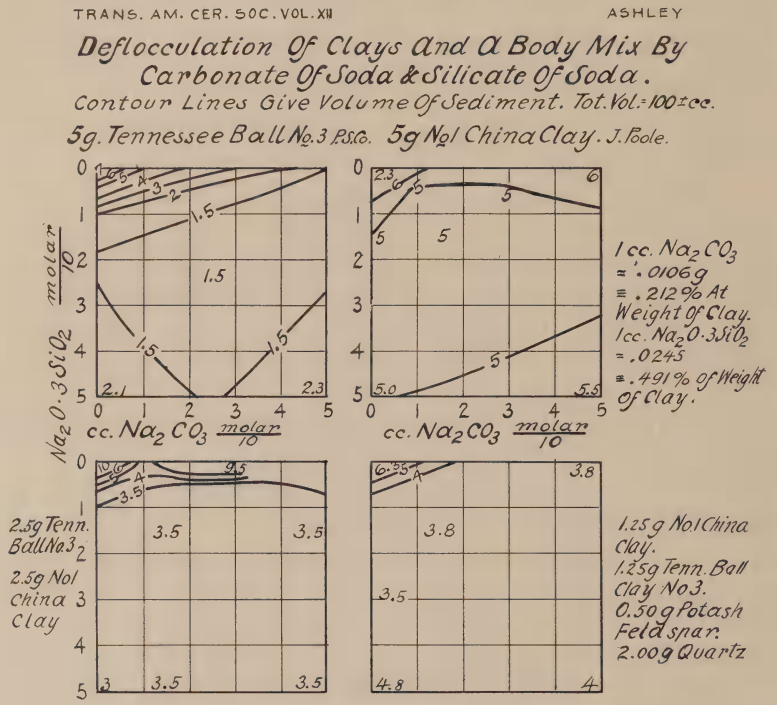
TRANS. AM. CER. SOC. VOL. XII
ASHLEY
Deflocculation Of Clays And A Body Mix By Carbonate Of Soda & Silicate Of Soda.
Contour Lines Give Volume Of Sediment. Tot. Vol. = 100 cc.
5g. Tennessee Ball No. 3 P.S.C. 5g No 1 China Clay. J. Poole.
Na2 0·3SiO2 molar/10
cc. Na2 CO3 molar/10
1 cc. Na2 CO3 = .0106 g = .212% At Weight of Clay.
1 cc. Na2 0·3SiO2 = .0245 = .491% of Weight of Clay.
2.5g Tenn. Ball No. 3
2.5g No 1 China Clay
1.25 g No 1 China Clay.
1.25 g Tenn. Ball Clay No 3.
0.50 g Potash Feldspar.
2.00 g Quartz

Fig. 15

In studying Fig. 15, one naturally tries to find what ratio of sodium carbonate to sodium silicate is most advantageous, or whether one should be used exclusively. The reasons are not evident from the diagram.

If sodium carbonate is used alone, the slip has a high surface tension, and the stream poured into the mould breaks into numerous drops. This causes the entanglement of air bubbles. Wherever one of these air bubbles gets into the ware, a crack will develop, and a piece of ware be ruined.

If sodium silicate is used alone, the slip is liable to flow in strings like thick syrup.

A proper balance between these two effects is secured by using a suitable mixture of the two reagents. The slip will then pour in a clean-cut solid stream, without any tendency to draw in air bubbles.

The writer is informed that some three plants making sanitary ware of fireclay have tried and abandoned Weber's process. Their difficulty was said to be, (1) that the ware made by the process was "rotten," or lacking in strength, (2) that the fine material of the clay seemed to collect at the surface leaving only large grains in the center, (3) that the ware stuck to the moulds, and (4) that the plaster of the moulds was rapidly attacked.

The first and third objections indicate that the plasticity was too thoroughly destroyed, and that it would have been better to use less reagent, and retain some of the plastic strength of the clay.

The fourth objection indicates the use of reagent in excess of the amount that the clay would react with.

The second and third objections, the writer has found to occur with a No. 1 fireclay treated with just sufficient reagent to give maximum sol formation. In the writer's experiment with this fireclay the water requirement was the same with or without the alkaline condition. It would appear that for the casting process a certain amount of shrinkage is essential, in order for the ware to free itself properly from the moulds; that the clay must originally have sufficient of the constituent that shrinks (colloid), and that the shrinkage must not be unduly suppressed by the alkaline addition.

Plasticity.

While the best condition for casting appears to be short of total deflocculation, the converse is not necessarily true for plastic working. It is true that the gel must be present in suitable amount for good working properties:

but whether the presence of some sol is advantageous is not known.

Further, it is not known what the effect is of varying the base or hydrogen in combination with the gel. It is, however, generally accepted that a clay becomes most plastic when it sours or becomes acid on ageing. This would indicate that the hydrogen gel is probably most plastic and the alkali gels least plastic.

Again, assuming a constant composition of gel, it is not known to what extent, if any, the presence of soluble salts is beneficial to plasticity, or whether they are detrimental. It is known that in weathering clays soluble salts are washed out, but it is not known whether the improvement in plasticity produced by weathering is due to the removal of soluble salts or to other actions that are known to be taking place.

All of these questions are now susceptible to experimental answer. When these answers are found they will probably be of great advantage to the industry.

Improvement of Clays.

If, for example, it should be found that an acid gel, free of soluble salts, is most desirable, it would be a simple matter to blunge up clays with a little acid (such as hydrochloric), let settle, throw away the overlying water, then wash by adding more water, again blunging a few minutes, letting settle, and running off the overlying water. This would remove the bases combined with the gel and also the soluble salts. It would improve the color of clays in which iron is one of the bases present (Rohland).

Similarly, calcium, magnesium, aluminum, iron, sodium or potassium might be introduced as chloride, or nitrate, if found desirable.

Thus, refractory clays may be made less fusible by substituting hydrogen or aluminum for such calcium, magnesium, iron, or alkalies as may be combined in their colloid matter.

Conversely, pottery clays may be made to mature at lower temperature by washing out the refractory bases with solutions of alkali salts, such as common salt, potassium nitrate, etc.

The addition of cobalt as chloride, sulphate, or nitrate to stain a clayware is not practicable: for the writer has found that only about half of it is taken up by the clay, and the rest remains with the filterpress water. As cobalt salts are rather expensive, this loss could not be viewed with complacency. Also cast ware could not be made with a body so colored; for in drying the cobalt would effloresce at the edges, and so color them more deeply than the rest.

Acheson[28] reports both deflocculation and improved plasticity from the use of tannin with clays, depending of course, on the use of less or more of the same and the nature of the clays.

Some of those that have tried to verify his results have encountered twisting and warping of ware, and so have condemned them. This is not just to Acheson; for in all processes of clayworking, skill is a very essential feature, and an imperfect mixture of the tannin could readily acount for the trouble reported.

It would seem as if some such experience as this led Keppler[29] to invent and patent his process of improving clays by, first, deflocculating with alkali; second, making an addition of colloid matter from humus; third, reprecipitating all together by the addition of acid.

Auclair[30] has patented the preparation of a pure crystalline ceramic paste by dissolving out the colloids with alkali, and removing the sol by filter-pressing.

Last year the writer gave reasons[31] for thinking the colloid matter of kaolin to have greater shrinkage than

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[28] Trans., 6, 31 (1904).
Brit. Pat. No. 7776 (3 Apr. 1907).

[29] German patent 201987 (Aug. 4, 1906); Chemical Abstracts, 3, 494 (1909).
Z. für angew. Chemie, 22, 526 (1909).

[30] French patent 372858 (Dec. 22, 1906); Chemical Abstracts, 2, 2436 (1908).

[31] Trans., 11, 550 (1909), U. S. Geol. Survey, Bull. 388, 53 (1909).

that of ball clays. It seems likely that safer body mixes could be made if all the colloid matter were derived from the ball clay. Hence, there seems good reason for the patent for removing colloids from kaolin.

The principal objection to ball clays is the amount of dirt carried by them. The worst of this material is in the shape of granules of iron-containing materials. It seems feasible to dissolve out the colloid matter of ball clays by suitable reagents, leaving behind a sediment containing most, if not all, of the discolorants. The colloid could be coagulated by acids when required, and could be made uniformly incorporated with other materials; for instance, the crystalline kaolin just mentioned.

Of course, these would be expensive processes; but the demands made upon the ceramic industry for high grade products are daily becoming more exacting; and for some purposes nothing is too good.

Fuller's Earth.

Fuller's earth may be defined as clay of especially high adsorptive powers or colloid content. There are many varieties.

The possibilities of improving or regulating it are many.

As the action is in many cases the exchange of bases, the first idea is to see to it that one's earth has the base best adapted to the specific purpose in view.

If it is not sufficiently porous for most effective working, it may be made so by heat treatment. This *sets*, or stiffens, the colloids without destroying their reactivity in most cases. It is the formation of a mineral charcoal, by driving off the most volatile constituents while preserving the structure. The gels of certain Fuller's earths, however, have their structure so altered by drying out even at ordinary temperature as to become worthless. This accounts for the differences of opinion noted in technical lit-

erature concerning the desirability or uselessness of heating Fuller's earth. The silicate and the humus colloids are probably unharmed by heat, while the iron hydrate, aluminum hydrate, and silica colloids probably lose in activity.

A concentrated Fuller's earth may be prepared from any clay by dissolving out the colloid matter and recoagulating it.

Sliphouse Water.

The soluble salts contained in sliphouse water may have very important effects.

The effect of hard water would be to make the clay slower in blunging than it would be in pure water. The blunging of difficult clays could undoubtedly be hastened by the addition of suitable alkali, but plasticity would probably be decreased.

The specific nature of the soluble salts may make special difficulties. It is well known that sulphates, whether derived from the clay or from the sliphouse water, tend to collect at the edges of pottery ware, to make "dry edges," on which the decoration is dulled or wholly spoiled. It would seem that the potter, equally as well as the brickmaker, could advantageously use barium carbonate in his mix to overcome the difficulties caused by sulphur. I would, therefore, propose that barium carbonate be added to pottery mixes to overcome dry edges.

If the sliphouse water takes up salts from the clays, rather than adds them, then by throwing away all the filterpress water, the quantity of soluble salts in the clays can be reduced.

When the new pottery at Newell, West Virginia, commenced operations, it used exactly the same materials (usually from divided shipments) and the same body formula as the plant that was then successfully operating at Laughlin, Ohio. But there was complaint in the clayshop of loss of ware. The help claimed that the body was not

as plastic as at the old plant. This condition lasted for some months, and gradually was lost sight of.

Now the clay bins were made of concrete, and there was some seepage of ground water inward. The blungers were lined with brick, laid in cement. The troughs from blunger to agitator and from sifter to agitator were of cement. The agitators were lined with cement. After some months' running, the bottoms of the agitators were so worn that it was necessary to reline them. In all of these places, then, the clays could take up free lime from the cement. This investigation has shown lime under certain conditions to be an effective deflocculating agent. Apparently it was responsible for the trouble at Newell. If such is the case, then in another such instance it would be easy to add acetic acid in sufficient amount wholly to overcome the trouble, and with no disadvantageous effects.

In this investigation I have been very fortunate in having the unfailing support and helpful suggestions of my chief, Mr. A. V. Bleininger, and the hearty good will of my associates, especially Mr. W. E. Emley, who assisted me for some months, and Mr. S. E. Young, who spent a shorter period on the work.

Preparation of Reagents.

The following describes how the solutions mentioned in this paper were prepared. They were not standardized, and were only approximately of the molar strength given:

Reagent	Formula	Strength	Preparation
Sodium hydroxide	$NaOH$	0.1 molar	4 grams, water added to make 1 liter.
Sodium hydroxide	$NaOH$	2.5 molar	100 grams, water added to make 1 liter.
Potassium hydroxide	KOH	0.1 molar	5.611 grams, water added to make 1 liter.
Ammonium hydroxide	NH_4OH	0.1 molar	3.34 cc. concentrated, diluted to 1 liter.
Aniline	$CC_6H_5NH_2$	0.1 molar	9.307 g., diluted to 1 liter.
Calcium hydroxide	CaO_2H_2	0.02 molar	slaked an excess of quicklime in boiling water, filtered, titrated with standard hydrochloric acid, diluted to 0.02 molar.
Barium hydroxide	$BaO_2H_2+8H_2O$	0.1 molar	31.56 g. made up to 1 liter, filtered.
Sodium silicate	$Na_2O:3\ SiO_2$*	0.1 molar	77.1 g. of conc. solution made up to 1 liter.
Sodium carbonate	Na_2CO_3	0.1 molar	10.6 g. soda ash made up to 1 liter.
Sodium oxalate	$Na_2C_2O_4$	0.1 molar	12.2 grams made up to 1 liter.
Ammonium oxalate	$(NH_4)_2C_2O_4$	0.1 molar	16.011 grams made up to 1 liter.
Potassium oxalate	$K_2C_2O_4$	0.1 molar	16.62 grams made up to 1 liter.
Tannic acid	$C_{14}H_{10}O_9$	0.1 molar	32.208 grams made up to 1 liter.
Sodium chloride	$NaCl$	0.1 molar	5.84 grams made up to 1 liter.
Magnesium chloride	$MgCl_2$	0.1 molar	9.524 grams made up to 1 liter.
Calcium chloride (fused)	$CaCl_2$	0.1 molar	11.1 grams made up to 1 liter.
Barium chloride	$BaCl_2+2H_2O$	0.1 molar	20.833 grams made up to 1 liter.
Sodium sulphate	$Na_2SO_4+10H_2O$	0.1 molar	32.223 grams made up to 1 liter.
Magnesium sulphate	$MgSO_4:7H_2O$	0.1 molar	24.653 grams made up to 1 liter.
Calcium sulphate	$CaSO_4:\frac{1}{2}H_2O$	Various	Slaked excess of plaster paris in water. Evaporated 20 cc. to dryness at 60°C. in platinum dish. Weighed residue to determine strength of solution.
Ferrous sulphate	$FeSO_4:7H_2O$	0.1 molar	27.807 grams made up to 1 liter.
Ferric sulphate	$Fe_2(SO_4)_3$	0.1 molar	40.000 grams made up to 1 liter.
Hydrochloric acid	HCl	0.1 molar	8.23 cc. (S. G. 1.19) made up to 1 liter.
Lead acetate	$Pb(C_2H_3O_2)_2+3H_2O$	0.1 molar	37.90 grams made up to 1 liter.

* Approximate Formula.

DISCUSSION.

Mr. Ries: I would like to ask Mr. Ashley one question. Did you use distilled water in that? Did you make any determinations to see what kind of materials would be carried off in solution?

Mr. Ashley: I elutriated once with distilled water, but the results were not appreciably different from any other runs. I have been unable, this being a one-man proposition, to do the amount of analytical work which should accompany such a paper. I have covered the ground but have omitted such laborious work as detailed chemical analyses of the products. I have here specimens which have settled and which show the line of demarkation between the colloidal matter and the crystal matter, as shown by the difference of color near the edge.

Mr. Ries: Did you make any microscopic examinations?

Mr. Ashley: We have of the crystal residues of the various clays after dealing with the deflocculating agent. In that way we have obtained crystal residues from fireclays, Florida kaolin, Tennessee ball clay, and from the various other things.

Mr. Purdy: Do I understand you to say that the volume of clay increased with the addition of water?

Mr. Ashley: Yes.

Mr. Purdy: What is that due to?

Mr. Ashley: Possibly due to the swelling of a spongy structure.

Mr. Purdy: Would the specific gravity be less after swelling?

Mr. Ashley: I am not prepared to make a statement on that. I do not know that the specific gravity changes greatly after being swelled up in water.

Mr. Purdy: I do not believe that your example is hardly an analogous one. If you note the true specific gravity of a swollen sponge it may not be less after swelling than before, but would not the clay particles that are

swelling the gels, as you call them, decrease in specific gravity as they swell?

Mr. Ashley: I am not prepared to say.

Mr. Purdy: On what basis do you say that they increase in volume?

Mr. Ashley: I have examined in under the microscope.

Mr. Purdy: You state that the clay in swelling pushes the grains apart. Would the clay as a whole, therefore, have a smaller specific gravity after swelling than before swelling?

Mr. Ashley: Yes, a smaller bulk gravity.

Mr. Purdy: Would the density of that clay be less in water than in a solution that would not effect the colloids and cause the swelling?

Mr. Ashley: If you wish to consider the clay saturated in water or in alcohol, assuming it to swell equal amounts, its bulk gravity in the alcohol would be the lesser, that is, the weight of the equal bulks would be greater with water in the pores and less with alcohol in the pores.

Mr. Purdy: I am not speaking of "bulk gravity." I refer only to the specific gravity of the clay grains. Now if you take one sample of clay and shake it up in water and another sample of the same clay in ether, alcohol, or coal oil, and the clay appears to occupy a larger volume in the water, the specific gravity ought to be less in the water than in these other solutions.

Mr. Ashley: Yes; if by that you mean that the bulk specific gravity, that is, the weight of the clay plus that of the water that swells it up, divided by the volume of the swelled up mass, using gram and centimeter units. Of what do you speak?

Mr. Purdy: I mean of the true specific gravity. You are dodging the issue when you speak of "bulk specific gravity." You know as well as I do how specific gravity of powders are made. Now if you shake samples of powdered clay in water, ether, alcohol, etc., would the specific

gravity of the clay be the same with each of the liquids when in one solution the particles hydrate and in the others they remain unchanged in volume?

Mr. Ashley: I do not know what the true specific gravity of the colloid matter is.

Mr. Purdy: Of course not, because you know nothing about the supposed colloids in clays except by indirect inferences. You state that the grinding of any material in water would introduce into it the jelly-like substance. Now, I want to know where you get your jelly-like substance by mere grinding?

Mr. Ashley: The effect of the grinding is to expose fresh surfaces of these minerals upon which the water has a hydrating effect, forming the colloidal hydrates, and in that way the amount of colloidal matter is increased in the grinding. Our friend, Mr. Cushman, presented to this society on the grinding of feldspar an opinion on this.

Mr. Purdy: He was not grinding flint. I am asking you about flint. Have you made the colloidal silicic acid by grinding flint? Cushman did not develop colloids according to any of his own statements. I am asking you about flint.

Mr. Ashley: It is a well known fact that the longer "flint" is ground the more sticky and inclined to cake it becomes, and with such fine grinding a caking characteristic is almost invariably a sign of the presence of colloidal material.

Mr. Purdy: You are taking the caking as evidence. You do not admit that very fine particles will do the very same thing.

Mr. Ashley: I think these particles which I am discussing, these colloid particles, are very fine.

Mr. Purdy: That is what I am leading to. Are your particles rough jellies, or fine particles?

Mr. Ashley: They are fine particles but they also have these characteristics which we know as colloidal.

Mr. Purdy: Do they swell up when dampened?

Mr. Ashley: When wetted.

Mr. Purdy: I doubt that. Mr. Bleininger spoke of preheated clays having the same colloidal content as before heating and yet do not shrink and crack as badly. How do you explain that?

Mr. Ashley: If we take a sample of glue, for example, and heat it up to a sufficiently high temperature with exclusion of air, that glue will change over to charcoal. Charcoal is a "set" colloid. It retains, in a measure, in a permanent form the structure of the substance from which it was prepared. It no longer shrinks and swells, nor can it form a sol. These properties can be restored only by extensive chemical reactions. But it does retain the characteristic colloidal properties of absorption and adsorption.

The preheated clay is a mineral charcoal, so to speak. The more volatile constituents of the clay gel have been driven off, the structure is preserved much the same, the adsorptive power is practically the same, but the ability to shrink and swell is cut down.

Mr. Purdy: I fail to see your analogy. You have taken these colloids from the true jelly-like condition over to a dry condition consisting of particles but which still retain power of adsorption. Your colloidal proposition in preheated clays then is different from that in flint. In preheated clays, according to your statement, the colloidal particles do not swell while in ground flint they do swell. How did you arrive at this conclusion? If by adsorption experiment alone, will you explain the phenomena of adsorption for instance in charcoal?

Mr. Ashley: The adsorption by charcoal I consider to be a case of chemical metathesis largely, an exchange in which the charcoal gives up something and usually receives more in exchange.

Mr. Purdy: Does the charcoal react with the gels?

Mr. Ashley: Hundreds of experiments have been performed in many laboratories on the reactions of char-

coal with solutions. I have heard it strongly doubted by very able chemists whether a charcoal of greater purity than 95% carbon has ever been prepared. The impurities may easily be 10% or more. Their isolation and study appears to present great difficulty. Nevertheless some progress has been made, and some of the separated substances have been shown to have similar precipitating power to that commonly attributed to charcoal.[32]

Mr. Purdy: The investigators of that subject have not come to any conclusion as to the nature of the phenomena of adsorption of charcoal. There are pretty nearly as many opinions as there are investigators.

Mr. Ashley: The investigators are pretty well divided into two groups—those who think adsorption a physical phenomenon and those who think it chemical precipitation.

T. Brailsford Robertson, of the University of California, in an elaborate paper[33] has recently shown that the mathematical equations used by the physicists to represent the observed facts of adsorption are but special cases of the mass action law of chemistry; and are in no wise inconsistent with the chemical explanation, but rather strengthen it.

Mr. Purdy: There is very little agreement on the subject. I would like to ask Mr. Ashley another question. In your work, have you seen the particles at all, that is, the molecules?

Mr. Ashley: Picton and Linder[34] expressed the belief in 1892 "that there is a continuous series of grades of solution passing without break from suspension to crystallizable solution." Mayer, Schaeffer, and Terroine[35] found the addition of traces of alkali to an ultramicroscopic suspension had the effect of diminishing the size of the colloidal granules if the solution is negative, and the

[32] Glassner and Suida; Annalen, 361, 353 (1908).
[33] Zeitschrift für Chemie und Industrie der Kolloide, 3, 49 (1908).
[34] J. Chem. Soc., 61, 171 (1892).
[35] Comptes rendus, 145, 918-920 (1907).

addition of acid produced the inverse effect. H. R. Proctor[36] states "In the typical crystalloid solution of an electrolyte, the dissolved body is separated into its molecules, and to a large extent into individual ions, while in the colloid sol the units of distribution are either large and often conjugated molecules or more frequently minute particles composed of many molecules united by cohesive attraction. These grade into each other. It is by no means impossible that very large molecules or molecular aggregates may displace and polarize light, and may even be made visible by the ultra-microscope.

A Coehn[37] has verified the earlier observation of Lobry de Bruyn[38] that this is at least partly true in the case of sugar. W. H. Brewer[39] said "Those substances which retard the 'Brownian movements' hasten the precipitation," applying the remark to fine grains of sand, flocculent clays, and pulverized charcoal. J. Perrin[40] has carefully measured the "Brownian movements," and finds them to be of exactly the magnitude that the kinetic theory gives for the movements of molecules of the size of the particles that he studied.

With the closely agreeing observations of these and other investigators at hand, I have no doubt of the existence of the large molecules described in today's paper.

Mr. Purdy: Are your colloids suspensions or are they solutions?

Mr. Ashley: Colloidal solutions. A solution is homogeneous in this sense — if two equal portions of sufficiently large size are taken each will have the same composition as the other. But if you talk about the ultimate composition of a solution, it is not homogeneous but heterogeneous, say a solution of common salt. It contains water molecules, a portion of which are broken down into hydro-

[36] Chemical News, 98, 152, 167, 175 (1908).
[37] Z. Elektrochem., 15, 652-4 (1909).
[38] Rec. trav. chim., 23, 155 (1904).
[39] Mem. Nat. Acad. Sciences, 2, 165 (1883).
[40] Ann. chim. phys., 18, 5-114.

gen ions and hydroxyl ions, also sodium chloride molecules, a portion of which are broken down into sodium and chlorine ions. Further, some of these ions recombine to form sodium hydroxide and hydrochloric acid. The combinations are being made and broken at a furious rate. The ultimate structure of a solution is homogeneous only as an average of a sufficiently large number of molecules.

Clay sols are true suspensions; they are at the boundary where solution and suspension overlap, and are identical.

Mr. Purdy: The only investigator who has actually seen these particles by aid of an ultro-microscope has defined the substance as very fine particles, the very things that I described last year as being responsible for plasticity. These very fine particles are what makes up the so-called colloids. This substance feels like jelly, simply because these particles are too small to be felt. They simply slip over one another without appreciable displacement between the fingers. It is merely the suspending of very fine particles—grinding them down to the limiting value in smallness. Colloids in the clay are largely particles in suspension. Nine-tenths of the paper that you have heard today is in direct argument of the point I argued last year and which I still favor. I have not made any personal investigations this year upon the subject, but I have a list of references that cover two or three letter sheets and which support the very views that I have supported, and about one-half of them say the very things that I have said concerning the plasticity and in favor of colloidal suspensions.

Mr. Ashley admits that if clay swells up when wetted, due to swelling of the colloids, it would have a smaller specific gravity in water than in ether or alcohol. Barus disproved that such was the case. He obtained no difference in specific gravity of clays in the different solutions showing that the clay particles do not swell when wetted with water. That is, there is no appreciable hydration when clays are mixed with water.

Mr. Ashley contends further that the true specific gravity of a sponge or any other cellular body that swells when wetted is not changed thereby. I agree with him in that, but he does not contend that his clay colloids are like sponges. He says that they swell up by becoming hydrated. If this is so, then I contend that the clay swollen by hydration will change in true specific gravity. He has not established the fact that difference in true specific gravity of hydrated silicic acid and the same when dehydrated is proportional to the difference in water content.

He refers to the caking, etc., of finely ground material as evidence of presence of colloids. Metallurgists do not consider this same phenomena in slimes as being due to colloids. They claim it is evidence only of very fine grains. Here again he claims hydration of the fine flint particles. He does not prove it.

I presented data showing close comparison of volume of excess water required for plasticity and size of particles in several clays. I demonstrated that that volume of excess of water equaled the calculated volume of water that would be held about the particles by molecular attraction as in Grout's theory of plasticity. It was this envelope of water about the particles that I claimed as the cause of swelling the clay mass and not swelling of the individual grains. Bourry, I find, made this same point.

I do not disclaim belief that clays contain salts that will hydrate. I *do* disclaim knowledge of any evidence having been presented that permits anyone to claim hydration of these salts as cause for plasticity.

You can not compare effect of fine grinding of flint which is very slightly (if at all) dissociated by grinding in water, with the grinding of feldspar that is comparatively easily dissociated.

If colloids are in the main fine particles, then we are agreed. Why not call them fine particles rather than by the generaly misunderstood and bewildering term—colloid? Why not drop the discussion of gels and sols and call your colloids by their correct names—fine particles?

Since Mr. Ashley admits his colloids to be of the colloidal *suspension* type, I am led to believe that he has allowed himself to be lost in an experimental chemistry maze by deductive reasoning from premises that have only an *apparent* bearing on the question under discussion. His finding that the colloidal content of clays is not altered by preheating, notwithstanding the fact that a "profound change" is caused in the plasticity and drying shrinkage, confirms this belief, for here he can no longer sustain the hydration hoax. His claim to understand the phenomenon of adsorption, and his total disregard of the physical phases of this unique property of charcoal and clay particles does not strengthen his position.

In closing, permit me to remind you that Mr. Ashley has succeeded very well in at least one thing, and that one thing is the presentation of data that completely spoils his elaborate method of measuring the plasticity of clays and giving to the clay a numerical plasticity value. I ridiculed that last year. I need not do so this year, for on preheating clays Mr. Ashley finds plasticity materially decreased but colloidal content unchanged. His modulus is, therefore, by his own testimony, discredited.

Mr. Ashley: On the contrary, I consider this year's work to confirm last year's assertion that plasticity is given by "relative colloids $\times$ air shrinkage $\div$ surface factor." If the preheating is carried so far as completely to destroy the air shrinkage, the expression reduces to plasticity $= 0$, even though the adsorption of dye shows a considerable colloid content (of set gels).

Moreover, the dye selected for the measurement of colloid content, malachite green oxalate, is probably the best in existence for the purpose. It is a salt whose base is a complex ammonia that forms insoluble compounds with the colloid acid radicals, while its oxalate radical forms insoluble oxalates with all the bases that keep clay in the coagulated condition. Therefore, its reaction with colloid matter is very complete. It fails indeed (is de-

colorized) with alkaline clays, which however are not included among the clays used for the better classes of clay wares. As both the sulphate and chloride of this dye are soluble in water no serious interference can be ascribed to such soluble salts as occur in clays. No other dye is so free from objections and so well suited for colloid measurements.

THE WARPAGE OF ROOFING TILE CLAYS.*

BY

WOLSEY G. WORCESTER, Columbus, Ohio.

In a search of the available ceramic literature, very little could be found pertaining to the above property of clays.

With a previous knowledge of the troubles encountered by the roofing tile manufacturer from the warpage of his ware while under fire, much of the following work has been directed to the determination of those clays most likely to prove troublesome and, if possible, to point out by pyro-physical tests the clays to be avoided when making a selection of clay for roofing tile manufacture.

In the past the universal opinion has been to class warpage with shrinkage; that is, a clay having a high shrinkage would be classed as one that would deform badly.

In a general way, this may possibly be true, but such a theory leaves very much to explain in studying warpage. In projecting this investigation, it was believed that the warpage of a clay could be attributed chiefly to the viscosity of that clay resulting from its mineralogical make-up. By the term viscosity is meant the degree of fluidity of the clay, in flowing or bending while under heat. For instance, tar is said to be a fluid of high viscosity, while water compared to tar is of low viscosity. Thus clays with a high degree of viscosity would be expected to resist warpage, while those with a low viscosity, lend themselves freely of this trouble.

On the theory that mineralogical composition is instrumental in this defect, the following references were found bearing more or less directly on the situation:

* By permission of Dr. J. A. Bownocker, State Geologist of Ohio.

Influence of Feldspar. That complete vitrification is not necessary to the development of warpage has been shown by Day and Allen[1] in a paper upon "The Ismorphism and Thermal Properties of Feldspars."

The above writers, in an attempt to study the viscosity of feldspars at their melting point, prepared slivers, about 30 x 2 x 1 mm., of the feldspars. These slender trials were then spanned across small empty platinum crucibles, and placed side by side in the furnace. These exposed crystals were heated to 1225° for three hours. When removed they were completely amorphous (melted) but retained their position with hardly a sign of sagging.

Other slivers were heated in some instances to 1300° for a few moments, and while at this temperature a platinum rod was inserted through a hole in the top of the furnace and allowed to rest as a load upon the middle of the crystal bridge. Under this load the slivers gradually gave way.

Slides cut from these trials showed no squeezing out of the melted portion between the crystal fragments on the side toward the center of curvature, or open cracks on the outer side. On the other hand there was evidence of the bending of the crystal as well as the vitrious portion. Further they say with a degree of confidence that the order of magnitude of the viscosity of the molten portion is the same as the rigidity of the crystals at these temperatures.

From the above it has been shown that while the feldspars had completely fused or melted, their viscosity was so high that deformation did not take place until a load had been applied.

While Day and Allen have shown that pure crystals of feldspars are extremely viscous, the action of these same feldspars in connection with a mineral mixture like ordinary clays may become quite changed. In the case of clays the feldspar may act as a flux or solvent to some por-

[1] American Journal of Science, Vol. XIX, p. 122.

tions of the mass and form glassy compounds that may be of low viscosity.

This glassy compound could have a low viscosity and still not cause deformation in the ware. In such a case the glass would be formed throughout the body without affecting a complete fusion of the latter. In other words, the glass could form and drain down or away from the mass, leaving it a skeleton unchanged, and, with the same degree of rigidity or viscosity that it possessed before the glass was formed. Examples of this are seen in bricks which stick together upon burning, and, at the same time, do not show any signs of kiln marking.

On the other hand, should the fluxes and the other mineralogical ingredients of the clay be of the proper proportions and condition to form a vitrification of the entire mass into a compound of low viscosity, a high degree of deformation would result.

The action or influence of feldspar upon an ordinary clay is unquestionably a matter of condition, depending upon the size of grains of the feldspar and their relation to the other ingredients. Should the feldspar be present in relatively large grains, its influence would largely be that of resistance to warpage, while the same quantity of feldspar finely pulverized and intimately mixed throughout the mass could cause a rapid reduction in the degree of viscosity of the clay as a whole.

Influence of Mica. The extent to which mica influences the viscosity of a clay is not definitely known. Its action as a fluxing ingredient has, however, been quite thoroughly studied.

Stull[2] has shown that mica when finely ground has practically the same fluxing power as feldspar. Hence when present in a clay body as a fine powder, mica may affect a fusion of the ingredients, and may act largely as feldspar does on the resulting solution.

In large flakes, however, it may act directly opposite.

[2] Transactions American Ceramic Society, Vol. IV, p. 225.

It is not at all uncommon to find flakes of mica remaining unaffected in hard-fire biscuit ware, proving that in large grains mica does not act as a flux at cone 8. Thus, if distributed throughout a clay mass in relatively large pieces, it may have a strong action upon the viscosity of the clay by its slowness to react with the other ingredients.

Mica taken alone requires about cone 13 to melt it, as shown by Rieke.[3] When present in ordinary clays or shales, burning at or near cone 1, it is therefore not likely that mica assists very greatly in softening the body, but is more apt to increase its degree of viscosity as a sterile ingredient.

Influence of Alumina. Purdy[4] says that Al_2O_3 not only raises the actual period at which fusion is completed, but also causes the wares made from aluminous clays to soften and deform very slowly. This slower softening and deformation of the ware he attributes to an increase in viscosity of the mass caused by the alumina.

The same writer has shown[5] that the addition of Al_2O_3 as a constituent in a stone ware glaze up to a proportion of alkali and alkaline earths to alumina of 2.5 to 1, not only rendered the glaze more fusible, but also less viscous. The addition of alumina above this proportional amount increased the refractoriness of the glaze if not its viscosity.

That additions of alumina to slags and glasses causes the viscosity to rise is a well known fact. Frink, in a paper, "The Effects of Alumina on Glass"[6] points out that a glass containing from 3 to 5% of alumina will have a less tendency to take the imperfections of the mold than a glass containing no alumina. In other words, the viscosity of the glass containing the alumina is higher.

From the above examples it can be seen that the effect which alumina may have upon the viscosity of a ceramic

[3] Sprechsaal No. 38, 1906.
[4] Bull. 9, Ill. Geo. Surv.
[5] Trans. A. C. S., Vol. V.
[6] Trans. A. C. S., Vol. XI.

mixture will depend largely upon its proportion to the other ingredients.

Influence of Magnesia. In a paper "The Influence of Magnesia on Clay"[7] it has been pointed out that magnesia, when added to a shale, has very greatly widened the vitrification range of that shale, as shown by the following table:

TABLE I.

No. of Test	Mixture	Absorption			
		Cone 05	Cone 1	Cone 3	Cone 5
C—1	Shale 100, Whiting 25.....	21.9	Melted	.....	.....
C—2	Shale 100, Whiting 12½...	20.4	Vitrified	Melted	.....
C—3	Shale 100, Magnesite 21 .	32.8	7.3	Vitrified	Shape Retained
C—4	Shale 100, Magnesite 10½.	28.4	.32	Vitrified	Slightly Swelled
C—5	Shale 100, Dolomite 22....	22.4	.78	Partially Melted	Melted
C—6	Shale 100, Dolomite 11....	17.7	11.5	Blistered	Melted
	Shale, without additions...	12.0	12.1	Blistered	.....

It will be observed that C—3 shows a good degree of vitrification at cone 1, is completely vitrified at cone 3 but still retains its shape at cone 5.

C—4, while only containing one-half as much magnesite, acts very much the same as C—3.

The shale, the shale-whiting and the shale-dolomite mixtures failed completely at cone 3 with a loss of shape. It can therefore be seen that the magnesite has very matrially raised the viscosity of the shale, while the whiting and dolomite have tended to produce the opposite effect.

The same writer in a brief review of a paper by Dr. Mäckler before the German Society for Clay, Cement and Lime Industries, says that "the action of magnesia on clays is a subject to which little attention has been paid; but, it was shown that exceedingly valuable properties are imparted to clays carrying this element naturally or artificially. The characteristics of clays of this nature are that they may be made into ware of extreme lengths and

[7] Trans A. C. S., Vol. V, p. 130.

with very thin walls, which may be very nearly vitrified, and still be kept perfectly straight and true."

Other ceramic investigators have found widely different results in the use of magnesia as a flux. Some claim that it is very active, while others claim not. In a general way it is considered as increasing the viscosity of ceramic mixtures. In the metallurgical field magnesia is said to have a strong effect upon the viscosity of the slag.

Purdy[8] says that the only known facts concerning the influence of magnesium oxide in ceramic mixtures are: (1) magnesium oxide increases viscosity; (2) magnesium oxide causes slower rate of fusion, at least when it is the predominating flux; (3) clays which make a good paving brick contain a larger amount of magnesium than calcium oxide; (4) the Italians are now making low-fire porcelain of which toughness is a special feature, and in which magnesium is the only RO present.

Influence of Lime. While the effect of lime on kaolins has been very carefully investigated by Dr. Rieke[9], it was for the greater part a study of the fluxing power of the lime, so that little light is thrown upon the manner in which lime may influence the rate or amount of warpage in ordinary clays and shales.

The above investigator has shown, however, that a mixture of kaolin and from 1 to 10 per cent calcium carbonate has a comparatively wide vitrification range and a slow fusion, while in mixtures of over 10% calcium carbonate the body does not vitrify until late and then melts or fuses very suddenly.

In either case it is more than likely that the calcium carbonate will act as a retarder of warpage up until the time when it becomes strongly active as a flux; from that period on, it is not at all improbable that lime causes a low viscosity in the ordinary clays. Strong evidence of this can be seen on every hand where high calcareous clays

[8] Bull. 9, Ill. Geo. Surv.

[9] Sprechsaal No. 38, 1906.

are being used; the over-burned ware is invariably in a hopelessly distorted condition.

That lime will prevent warpage to a large degree in the early stages of vitrification is clearly brought out in the No. 3 or Cramer warpage trials, of clays E and N, to be described later. While these clays have developed but a small degree of deformation, their porosity, as will be noted, is still very high. The manner in which lime prevents warpage is without question directly traceable to its dry or slow fusion in the early stages of vitrification.

COLLECTION OF SAMPLES.

The clays used in this work were collected in every instance from roofing tile plants, either active or recently closed. The object in view was to have every type of clay represented that is in use in this country for the manufacture of roofing tile.

The samples, when of shale, were collected at the bank or immediately after it had passed the screen. In no case had any of them been pugged. The soft clays were, for the most part, collected at the end of the pug mill, owing to the fact that most of the manufacturers using clay find it advantageous to mix a small proportion of shale with the clay; and thus a correct sample of the mixture was obtained.

It is not believed, however, that the physical character of these clays had been materially disturbed by their preliminary passage through the pug mill.

TYPES OF CLAYS AND LABORATORY PREPARATION.

The samples collected and tested were as follows:

One Glacial Clay.
One Semi-glacial or Alluvial Clay.
One Alluvial Clay.
Ten Shales.

Tentative 6/4/18

~~How to~~
Would it be possible to
set the drying, burning
& total shrinkages
for clays by making
discs in place of bars and
get more consistent
results than with our
present method?
The circumference of the
~~disc~~ inside of the dry would
give the net length;
the circumference of the
dry bar; the dry length etc.
We would use our present
method for figuring out
the percentages.

first, next. All unfilled orders on our books and present existing contracts will be filled in accordance with the terms under which they were taken. New Orders will be accepted at the old prices for such amounts as we can deliver before the above date.

We thank you for many past favors we have received and wish to assure you that when normal conditions again exist, we shall be only too glad to meet them.

Very truly yours,

THE BALDWIN CHAIN & MFG. CO.

W. H. Gates Treas.

WHG:MLH

When the samples had all been collected at the laboratory they were ground in a small dry pan until sufficiently fine to pass a 20-mesh screen, this size representing about the average in practice. After screening, each sample was wetted down with water, and then sufficiently wedged to form a wad or ball. These wads in turn were wrapped in wet burlap and packed away in plaster damp boxes and left to sweat and soften for 48 hours. At the end of this ageing period each sample was thoroughly wedged on a clean plaster block preparatory to its shaping into the various trial pieces.

PRELIMINARY TESTS.

In order to determine the physical properties of the clays in question, the following tests were made:

1st. Determination of true specific gravity of the raw clays.

2nd. Amount of water required to develop plasticity.

3rd. Drying shrinkage.

4th. Burning shrinkage at various cones.

5th. Apparent specific gravity of burned trials.

6th. Porosity of burned trials.

Specific Gravity of Raw Clay.

TABLE II.

Clay	Specific Gravity	Clay	Specific Gravity	Clay	Specific Gravity	Clay	Specific Gravity
A	2.752	D	2.752	G	2.692	J	2.459
B	2.764	E	2.752	H	2.654	K	2.619
C	2.666	F	2.714	I	2.610	M	2.662
						N	2.550

These determinations were made by the pycnometer or specific gravity bottle.

"A pycnometer," as described by Purdy,[10] "is a small flask of known capacity, usually 25 to 100 cc. When filled up to a given mark with air-free water at normal room

[10] Bull. IX, Ill. Geo. Surv.

temperature, its weight is noted. The flask is then partly emptied, a known weight of clay added, and the whole carefully boiled to exclude all entrapped air, then cooled, filled up to the mark and weighed. By the formula, weight of dry sample (a) plus weight of bottle filled with cold air-free water (b) minus weight of bottle filled with sample and water (c), or a+b—c, will give the weight of water having the same volume as the sample, or true total volume of the clay particles. Knowing the dry weight and true volume of the grains, their composite specific gravity is readily calculated by the formula (dry weight÷volume).

A careful study of these specific gravities fails to show any relation between them and the warpage of their respective clays. They are added, however, that they may prove of help in some other direction.

Water Required for Plasticity.

The same trial pieces were used for the determination of the water of plasticity, the drying shrinkage, burning shrinkage, apparent specific gravity and porosity. These trials were made by expressing a 1″x 1″ column of clay through a die attached to a small hand plunger machine, the column being cut into 5″ lengths as it issued. In all, twenty trial pieces of each clay were run, thus affording duplicates. While still plastic, each trial was marked with its sample number, and shrinkage marks, 100 mm. apart.

Just prior to the marking with the shrinkage marks, each trial was carefully weighed on a chemical torsion balance, then, after being allowed to dry at normal room temperature until white dry they were placed in a drying oven and brought to a constant weight. Thus with the wet and dry weight of the various samples it was an easy matter to calculate the percentage water of plasticity by subtracting the dry weight from the wet weight and dividing the difference by the wet weight, which gave the following results:

TABLE III.

Clay	Per cent. Water	Clay	Per cent. Water
A	20.62	H	22.62
B	16.22	I	17.33
C	24.28	J	23.94
D	21.87	K	20.48
E	21.52	M	17.14
F	22.22	N	16.90
G	15.16		

Determination of Drying Shrinkage.

When the 1″ x 1″ x 5″ trials, which had previously been stamped with shrinkage marks 100 millimeters apart, had reached a constant weight in their drying, they were closely measured with a millimeter scale, and the resultant shrinkage calculated in percents of the wet length.

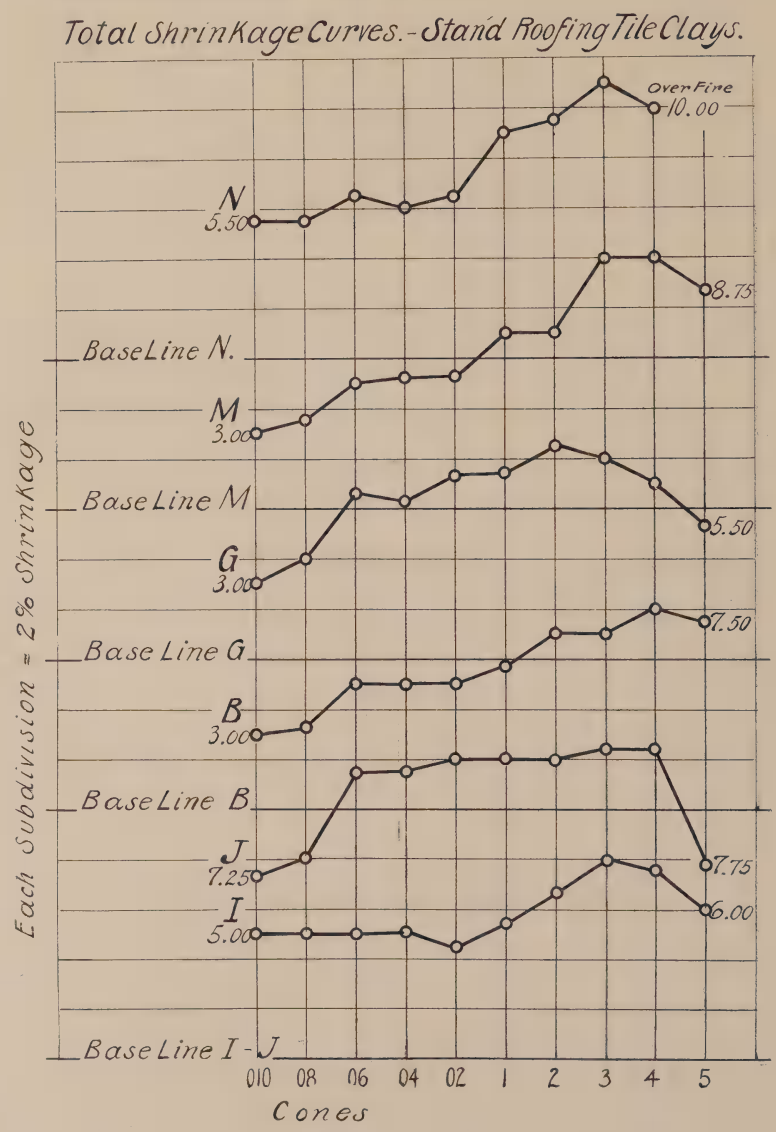
TABLE IV.

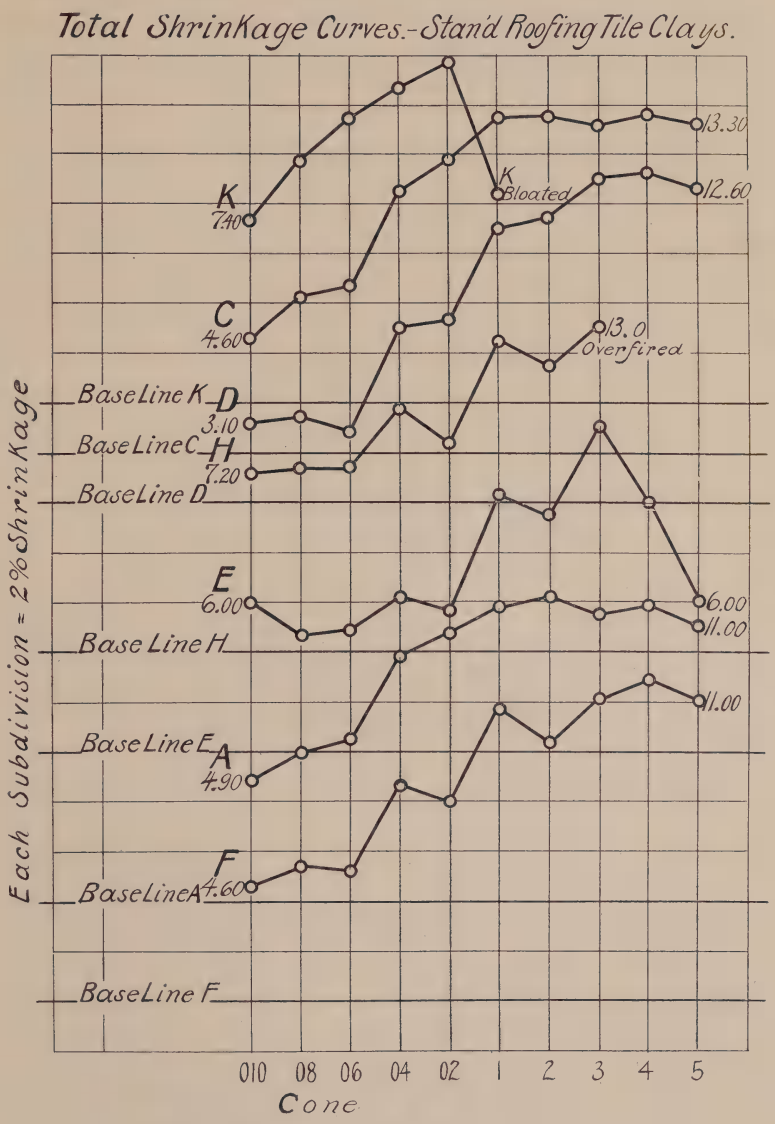
Clay	Drying Shrinkage	Clay	Drying Shrinkage
A	4.95	H	7.58
B	2.94	I	3.90
C	4.75	J	6.25
D	3.70	K	5.50
E	5.56	M	3.50
F	4.85	N	5.00
G	2.06		

Determination of Total Shrinkage.

The trial pieces, which had been used in the determination of the plasticity water and drying shrinkage, were next set in the muffle of a gas fired kiln in a manner such that two trials of each clay could be drawn out of the kiln at the following cones,—010, 08, 06, 04, 02, 1, 2, 3, 4, 5.

The length of time used in this burn was approximately thirty hours, the increase in temperature being distributed as evenly as possible over the time duration.


Total Shrinkage Curves.-Stand Roofing Tile Clays.
Over Fire
10.00
N
5.50
8.75
Base Line N.
M
3.00
Base Line M
5.50
G
3.00
7.50
Base Line G
B
3.00
Base Line B
J
7.25
7.75
I
5.00
6.00
Base Line I-J
Each Subdivision = 2% Shrinkage
010 08 06 04 02 1 2 3 4 5
Cones


Total Shrinkage Curves.-Stand Roofing Tile Clays.
K
7.40
K
Bloated
13.30
12.60
C
4.60
13.0
Overfired
Base Line K
D
3.10
Base Line C
H
7.20
Base Line D
E
6.00
6.00
11.00
Base Line H
11.00
Base Line E
A
4.90
F
4.60
Base Line A
Base Line F
Each Subdivision = 2% Shrinkage
010 08 06 04 02 1 2 3 4 5
Cone

To avoid as largely as possible any differences in the heat treatment of the trials and their respective cones, the setting was so arranged that each cone was set immediately with its corresponding trials. As the cones melted the trials were drawn from the kiln and transferred at once to a second kiln that was being held at red heat, in order to obtain more uniform cooling conditions. After all the trials had reached their respective cones and the transfer had been made they were allowed to cool and then removed from the kiln. Each trial was next measured with the millimeter scale previously used, giving the following per cent total shrinkage based on the wet or green length:

TABLE V.

Total Shrinkage, Standard Roofing Tile Clays.

Clay	Heat Treatment Expressed in Cones									
	010	08	06	04	02	1	2	3	4	5
A	4.9	6.0	6.6	9.9	10.9	11.8	12.2	11.6	11.9	11.0
B	3.0	3.24	5.0	5.0	5.0	5.75	7.0	7.0	8.0	7.5
C	4.6	6.3	6.7	10.5	11.9	13.5	13.5	13.2	13.6	13.3
D	3.1	3.3	2.9	7.0	7.3	11.2	11.6	13.0	13.2	12.6
E	6.0	4.6	4.9	6.2	5.6	10.3	9.5	13.0	10.0	6.0
F	4.6	5.3	5.3	8.6	8.0	11.8	10.3	11.0	11.9	11.0
G	3.0	4.0	6.5	6.25	7.25	7.50	8.5	8.0	7.0	5.5
H	7.2	7.6	7.6	9.7	8.3	12.5	11.3	13.00	.....	.....
I	5.0	5.0	5.0	5.0	4.5	5.5	6.75	8.0	7.5	6.0
J	7.25	8.0	11.5	11.5	12.0	12.0	12.0	12.25	12.25	7.75
K	7.40	8.80	11.40	12.70	13.82	8.23*	.....	.....	.....	.....
M	3.0	3.5	5.0	5.25	5.25	7.0	7.0	10.0	10.0	8.75
N	5.5	5.5	6.5	6.0	6.5	9.0	9.5	11.0	10.0	†

* Bloated. † Melted.

In plotting the above curves, efforts to divide up the clays into groups of similar behavior were not satisfactory. Each clay has therefore been plotted singly, though arranged in the order of decreasing total shrinkage value. The beginning and ending of each curve is marked with the proper percentage, from which the imaginery base line for each curve can easily be picked out.

By this method of plotting, the shape or contour of a number of curves can be easily and rapidly compared, and the commercial value of each can be ascertained quickly.

TABLE VI.

Burning Shrinkage of Standard Roofing Tile Clays.

Clays	Heat Treatment Expressed in Cones									
	010	08	06	04	02	1	2	3	4	5
A	0.05*	1.05	1.65	4.95	5.95	6.85	7.25	6.65	6.95	6.05
B	0.06	0.31	2.06	2.06	2.06	2.81	4.06	4.06	5.06	4.56
C	0.15*	1.70	2.10	5.90	7.30	8.90	8.90	8.60	9.00	8.70
D	0.60*	0.40*	0.80*	3.30	3.60	7.50	7.90	9.30	9.50	8.90
E	0.44	0.96*	0.66*	0.64	0.04	4.74	3.94	7.44	4.44	0.44
F	0.25	0.70	0.70	4.00	3.40	7.20	5.70	6.40	7.30	6.40
G	0.94	1.94	4.44	4.19	5.19	5.44	6.44	5.94	4.94	3.44
H	0.38*	0.02	0.02	2.12	1.72	4.92	3.72	5.42	†	....
I	1.10	1.10	1.10	1.10	0.60	1.60	2.85	4.10	3.60	2.10
J	1.00	1.75	5.25	5.25	5.75	5.75	5.75	6.00	6.00	1.50
K	1.90	3.30	5.90	7.20	8.32	**	....	....	....	....
M	0.50*	0.00	1.50	1.75	1.75	3.50	3.50	6.50	6.50	5.25
N	0.50	0.50	1.50	1.00	1.50	4.00	4.50	6.00	5.00	†

* Increase over dry size. ** Bloated. † Melted.

The above table of burning shrinkage was obtained by subtracting the drying shrinkage from the total shrinkage.

Determination of Apparent Specific Gravity of Burned Trials.

After obtaining the shrinkage on the trials burned at the various heat ranges or cones, they were broken so as to give pieces about 1½″ long. These pieces were placed in a drying oven for several hours, then removed a few at a time and weighed on a chemical balance, accurate to the second decimal.

They were next placed in pans of distilled water and allowed to soak with one end exposed for 24 hours. Following this treatment, and, while still in water, they were placed under the bell of a vacuum pump, where the air was

kept exhausted until the trials ceased to give off bubbles. Upon removing from the pump, each trial in turn was suspended from one pan of the balance used in making the dry weight, the wet or saturated weight was now taken, and, with the trial thus suspended a vessel of distilled water was raised up underneath until the trial was completely immersed; a weighing was again made, which gave the suspended weight in water.

To obtain the specific gravity after having the above weights, it was only necessary to apply the formula

$$\frac{D}{D-S} = \text{sp. gr.}$$

in which D = dry weight. S = suspended weight.

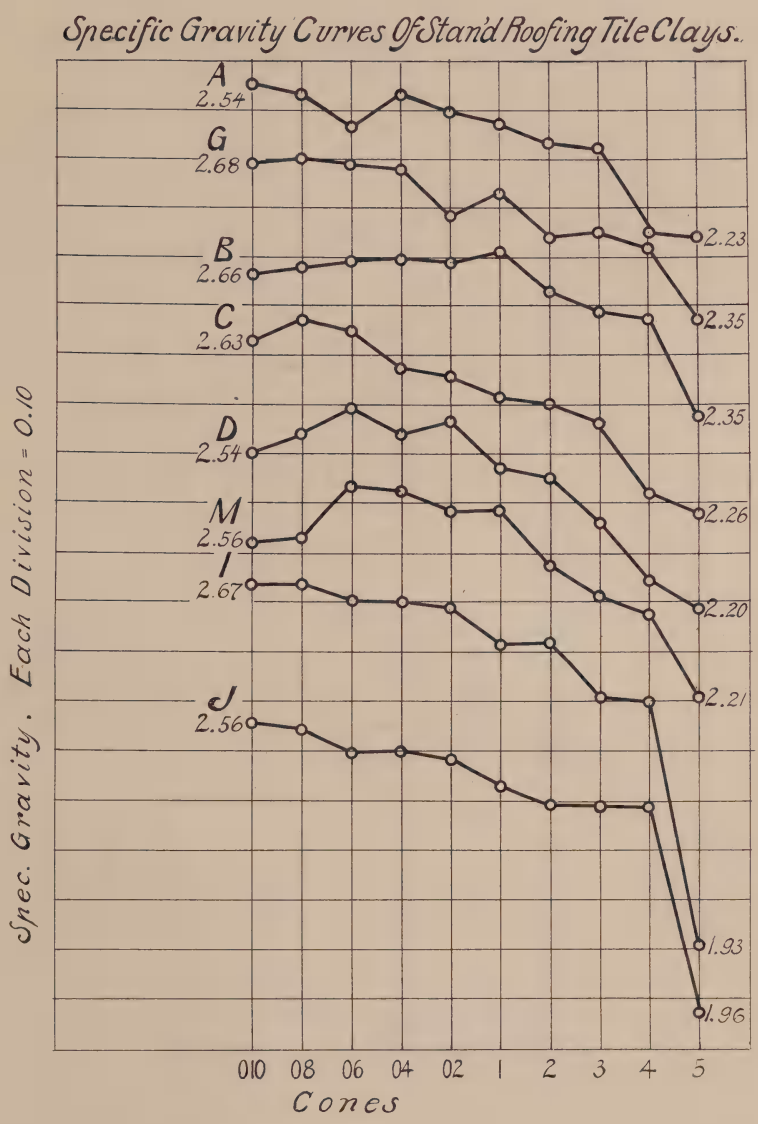
TABLE VII.

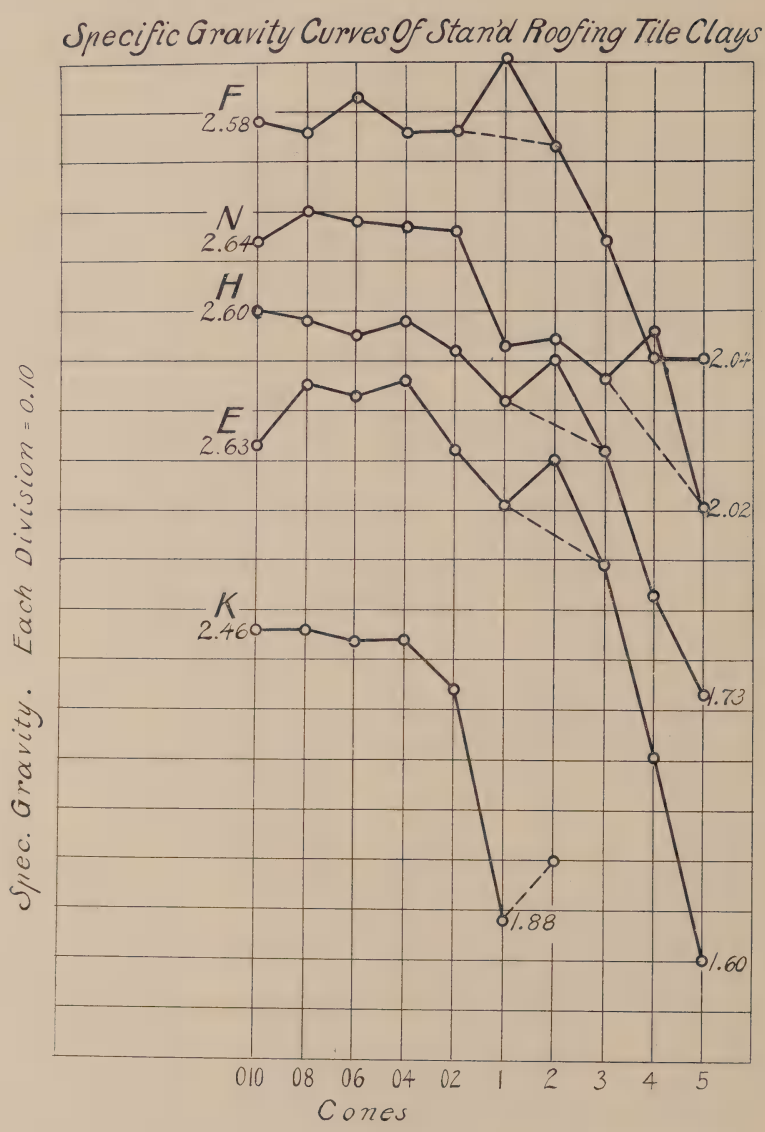
Specific Gravity, Standard Roofing Tile Clays.

Sample	Heat Treatment Expressed in Cones									
	010	08	06	94	02	1	2	3	4	5
A	2.54	2.52	2.45	2.52	2.48	2.46	2.42	2.41	2.25	2.23
B	2.66	2.67	2.68	2.68	2.68	2.70	2.61	2.57	2.56	2.35
C	2.63	2.66	2.64	2.56	2.55	2.50	2.49	2.45	2.30	2.26
D	2.54	2.58	2.63	2.58	2.60	2.50	2.47	2.40	2.28	2.20
E	2.63	2.75	2.73	2.76	2.62	2.51	2.60	2.39	2.05	1.60
F	2.58	2.56	2.63	2.56	2.56	2.71	2.53	2.34	2.06	2.04
G	2.68	2.69	2.68	2.67	2.57	2.62	2.53	2.54	2.51	2.35
H	2.60	2.58	2.55	2.58	2.52	2.42	2.50	2.32	1.93	1.73
I	2.67	2.67	2.64	2.64	2.63	2.55	2.56	2.45	2.44	1.93
J	2.56	2.55	2.50	2.50	2.49	2.43	2.39	2.39	2.39	1.96
K	2.46	2.46	2.44	2.44	2.34	1.88	2.00	*	....	....
M	2.56	2.57	2.67	2.66	2.62	2.62	2.50	2.44	2.41	2.21
N	2.64	2.70	2.68	2.67	2.66	2.43	2.44	2.36	2.46	2.02

* Floats.

For convenience, the clays are drawn on the curve sheets in the order of their reduction in specific gravity, from the maximum to the minimum of each clay. Thus clay A changes only 0.31 between its maximum and mini-


Specific Gravity Curves Of Stand'd Roofing Tile Clays.
A
2.54
G
2.68
B
2.66
C
2.63
D
2.54
M
2.56
I
2.67
J
2.56
2.23
2.35
2.35
2.26
2.20
2.21
1.93
1.96
Spec. Gravity. Each Division = 0.10
010 08 06 04 02 1 2 3 4 5
Cones


Specific Gravity Curves Of Stan'd Roofing Tile Clays
F
2.58
N
2.64
H
2.60
E
2.63
K
2.46
2.07
2.02
1.73
1.88
1.60
Spec. Gravity. Each Division = 0.10
010 08 06 04 02 1 2 3 4 5
Cones

mum. Clay E, on the other hand, changed 1.03 in specific gravity in the same heat treatment, showing that this clay was far gone in viscous bloating. No effort has been made to group these clays according to the actual numerical value of their specific gravity, as this is a function of their mineral composition.

A study of these curves shows a very considerable variety in their details, but the tendency is for each clay to attain a maximum, somewhere prior to cone 02, and thereafter fall away more or less sharply, as the sealed pores begin to affect the volume.

Clays A, G, B, C, O, D and M all have curves in which the reduction is moderate in amount, and occurs late enough in the firing to show that these clays have wide and safe vitrification ranges.

Clays F, N, H, E and K all show curves in which the reduction is large in amount and rapid in rate, and indicate clays of unsafe vitrification.

No standard of specific gravity for roofing tile clays, either in numerical amount or in rate of change can be set as the result of this inquiry, but by comparison of other clays with these, a similarity of general contour with the clays here known to be of good working quality would tend to confirm other sources of judgment.

Porosity.

The porosity was determined by substituting the dry, wet and suspended weights of the trials in the formula, by Purdy,

$$100\left(\frac{W-D}{W-S}\right) = \text{Percent Porosity.}$$

which gave the following table and curves:

TABLE VIII.

Porosity.

Sample	Heat Treatment Expressed in Cones									
	010	08	06	04	02	1	2	3	4	5
A	29.53	25.77	18.11	11.52	7.48	4.95	3.00	2.51	1.08	1.23
B	31.07	31.12	26.80	25.76	26.15	21.92	19.29	12.57	14.04	3.12
C	35.94	35.02	32.45	17.00	14.30	7.41	5.22	4.07	1.10	.98
D	32.85	32.03	33.39	24.59	13.04	12.62	10.12	2.62	.74	.80
E	38.42	39.87	39.34	41.67	40.10	12.50	26.46	1.90	2.72	1.33
F	33.99	31.83	33.48	23.65	24.61	12.08	16.83	2.93	.60	1.24
G	28.31	27.73	19.03	16.19	16.69	8.22	9.10	3.77	8.42	7.82
H	30.96	24.88	29.94	24.95	25.37	8.05	16.20	1.65	2.56	1.97
I	33.04	33.33	32.10	32.17	32.10	29.62	23.88	17.94	15.32	.52
J	24.55	22.98	11.22	9.30	9.15	7.41	7.17	7.40	7.88	9.21
K	17.53	14.48	8.24	5.77	1.71	.65	.80	*	*	*
M	29.88	29.42	28.49	28.73	27.74	21.43	10.73	3.66	3.10	.51
N	37.12	38.25	37.64	37.20	36.42	18.25	17.86	5.68	21.04	1.01

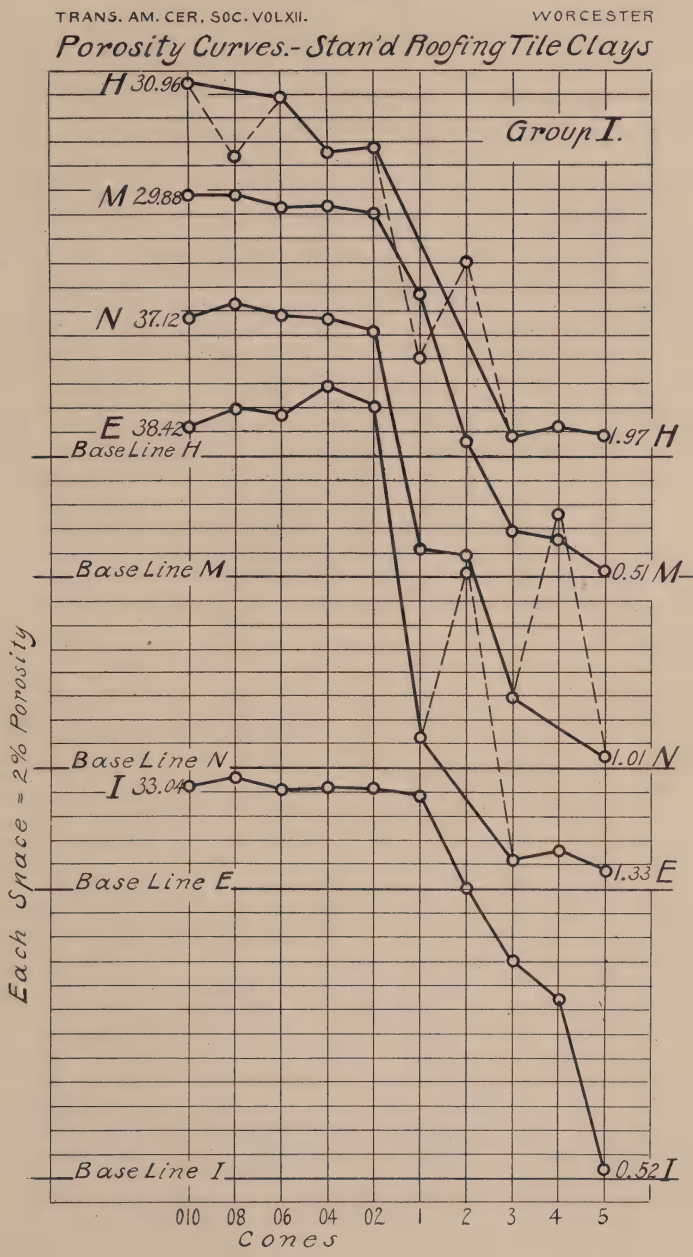
* Bloated.

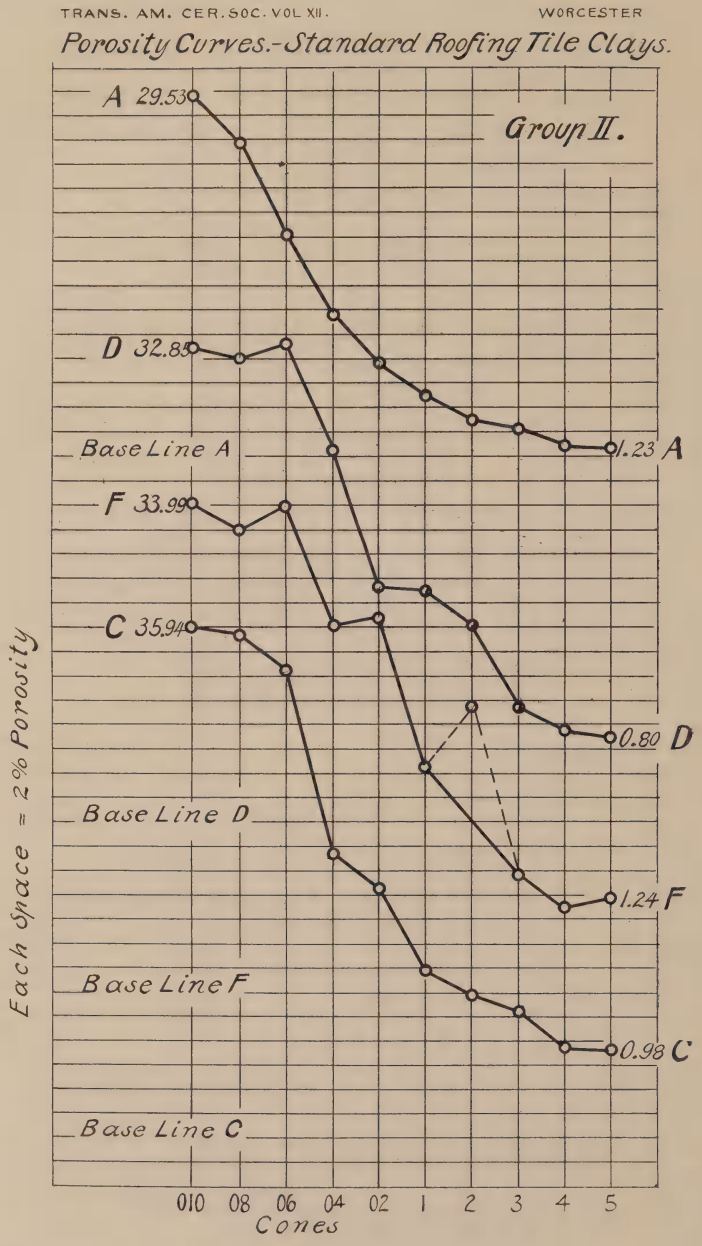
An effort has been made to classify the clays, in the study of their porosity, into three different groups as shown by the curves. Clays J and K, however, do not fall within the three general groups, and for convenience only they have been placed on the curve sheet, Group III.

Group I. This group is of exceeding narrow vitrification range. None of them show any marked change in porosity prior to cone 02, but immediately following that point the porosity drops very rapidly until cone 3 to 4 is reached, where the vitrification is practically complete.

These curves signify that the vitrification process or the mutual solution of the minerals of the clay does not begin early, but that it proceeds with great vigor when once begun.

It should be noted that there are some remarkable or erratic breaks in the curves of clays E and H at cone 2 and of clay N at cone 4. Since such irregularities are in most cases due to some discrepancy in the work or burning, it has been deemed advisable to plot them on the curves but to attach very little if any weight to them.


TRANS. AM. CER. SOC. VOL XII.
WORCESTER
Porosity Curves.- Stan'd Roofing Tile Clays
Group I.
H 30.96
M 29.88
N 37.12
E 38.42
I 33.04
Base Line H
Base Line M
Base Line N
Base Line E
Base Line I
1.97 H
0.51 M
1.01 N
1.33 E
0.52 I
Each Space = 2% Porosity
010 08 06 04 02 1 2 3 4 5
Cones


TRANS. AM. CER. SOC. VOL XII.
WORCESTER
Porosity Curves.-Standard Roofing Tile Clays.
Group II.
A 29.53
D 32.85
Base Line A
1.23 A
F 33.99
C 35.94
0.80 D
Base Line D
1.24 F
Base Line F
0.98 C
Base Line C
Each Space = 2% Porosity
010 08 06 04 02 1 2 3 4 5
Cones

Group II. The curves for these clays, A, D, F and C, show that they differ from Group I in two respects; first, their vitrification begins very early, second, their rate of vitrification does not progress as rapidly as that of Group I.

Clay F, which contains some lime, as do clays E, N and H of Group I, shows the same erratic break in its curve at cone 2 as clays E and H.

Group III. This group is represented by clays B and G, which show porosity curves that indicate a slow and wide vitrification range,—clay G more so than B.

As stated before, clays J and K do not belong to this group nor to either of the others. In a general way they conform to the curves shown in Group II, in the respect that their vitrification is quite rapid from the start.

WARPAGE.

In order to study the relative warpage behavior of the clays under test, three sets of trials were outlined. It was considered best to make the three sets in widely variant shapes that would require different setting, in order that if one set failed to develop warpage the others possibly would, and, in any event, that they might act as checks one upon the other.

Shape and Preparation of No. 1 Trials.

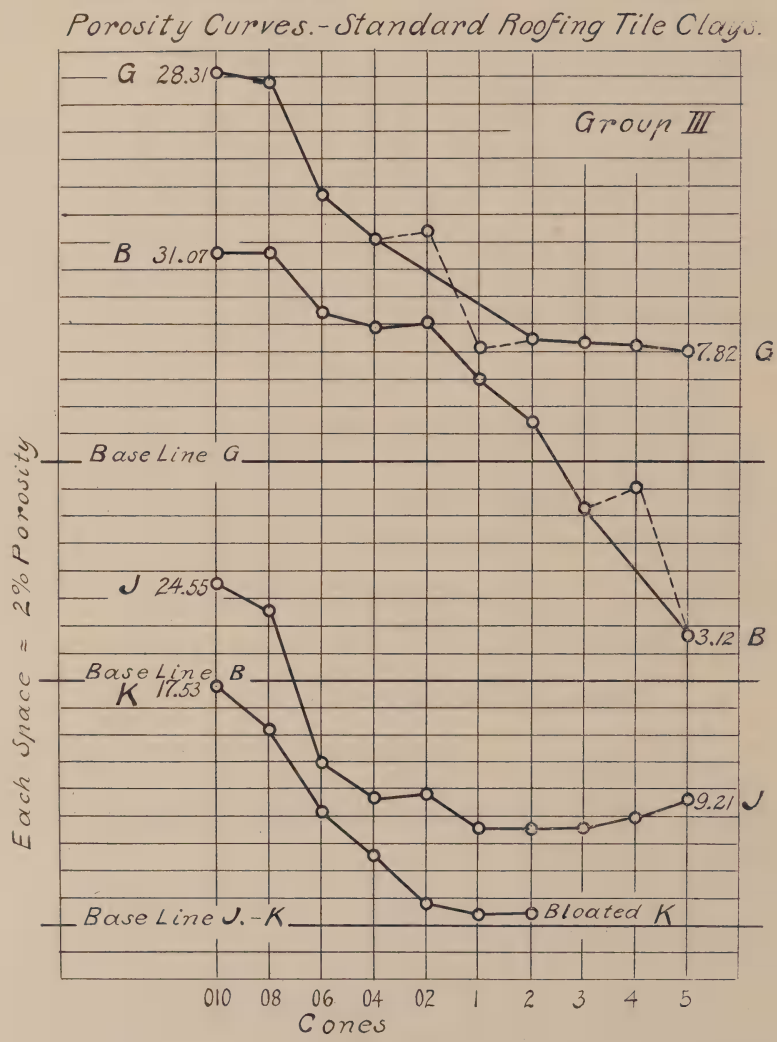
At the outset of this work it was the opinion that the highly warping clays could be detected by burning thin quarry tile, and noting their behavior. To this end, in the light of the results obtained, the work was, in a large measure, a failure.

In making the trials, the clays which had previously been pugged and then kept moist in a damp box, were removed from the box and thoroughly wedged by hand. When uniform, bats or blanks were batted out until they were $\frac{5}{8}''$ thick, and of such size that $4'' \times 4''$ tile could be cut

therefrom. The blanks were then dropped into a 4¼″x 4¼″ die on a hand screw press and firmly repressed until each was approximately ½″ thick. Upon removing from the

POROSITY CURVES—STANDARD ROOFING TILE CLAYS.

TRANS. AM. CER. SOC. VOL XII. WORCESTER



press the tile were placed upon perfectly straight wood pallets and allowed to dry at room temperature until white hard before placing in a drying oven for the final drying.

Shape and Preparation of Trials No. 2.

It is a well known fact among the roofing tile manufacturers that Spanish tile are very prone to twist or warp in their burning. That is, the end of the tile set uppermost in the kiln draws in, while the end resting on the sagger or kiln block becomes distorted or enlarged. With a previous knowledge of this, a set of trials were prepared that would approximate in shape the Spanish tile; they were half round in form, three inches long, three inches wide and one-quarter inch thick. These trials were made by hand pressing the clay into plaster molds, much care being taken to maintain a uniform thickness in the individual tile, and, from tile to tile.

To properly dry these shapes, pallets were constructed with strips or cleats to prevent the legs or sides of the trials from spreading while plastic.

Each tile was left on its pallett in an open room until white dry, whence it was removed to a drying oven for the final drying.

Shape and Preparation of Trials No. 3.

The form and methods employed in this set of trials were developed by Mr. E. Cramer, of Germany,[11] some years ago for the testing of clays while under heat treatment, but, it is not known that it has ever been used for that purpose in this country prior to the present work for the study of warpage. In form or outline the trials for this test were thin bars of clay, approximately 12″ long, 1¼″ wide and ½″ thick.

Knowing that it is impossible to produce uniform trial pieces by hand methods, it was deemed advisable to

[11] Kerl, p. 847.

make this set of trials by machinery. In order to do this, a flat shingle tile die 17/32″x 6½″ was attached to a small Mueller auger machine. The clay having been previously tempered was fed into the machine, and issued as a flat shingle column. This column was cut into 13″ lengths, thus giving tile or blanks 6½″ x 13″ x 17/32″. The blanks were placed on carefully selected straight pallets, and then cut lengthwise into strips approximately 1¼″ wide, then without disturbing they were allowed to dry at a slow and easy rate. When white dry, as in the case of trials Nos. 1 and 2, they were removed to a dryer and brought to bone dryness prior to setting.

Burning of Trials

Kiln Employed. The kiln used in making the burns for this work was a small down draft coke-fired kiln, not differing widely from the kiln shown in Purdy's paper, "The Pyrochemical Changes of Clays," Vol. IX, A. C. S. Trans., except that the kiln was some larger, holding approximately 300 common brick.

Number and Length of Burns. In planning the burns for the work it was deemed best to keep within the commercial heat ranges of the clays as far as possible. Hence four burns were decided upon—at cones 09, 07, 04 and 01—it having been shown by the preliminary tests that most of the clays would fall within these limits.

The duration of each burn was thirty hours or more, the heat being raised at a gradual rate, except for a short oxidation period. At the completion of each burn the fire was raked clean and the kiln allowed to cool in about 12 hours.

In each burn there were placed two trial pieces of each clay from the three different sets.

Method of Setting. It was in the method of setting that the three sets of trials differed most widely in the effort to induce deformation or warpage. It was expected that if trials No. 1 were set flat, the clays most likely to

warp would dish, while the low or non-warping clays would remain flat and straight. Fire clay blocks or tile were selected for their straightness, and were so placed in the kiln that the entire set of No. 1 trials could be spread out or set flat, one deep, over the surface of the fire clay blocks. The entire series was placed in the upper part of the kiln chamber where the flame or heat would play most directly upon the tile, while trials Nos. 2 and 3 were placed lower down in the kiln,

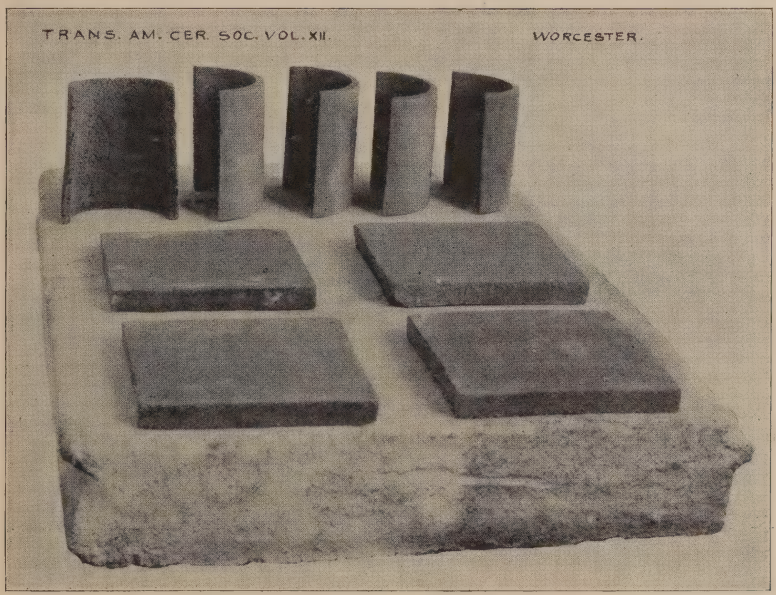


Fig. 1.

The half round trial to the left shows the characteristic warping or drawing in of the upper end over that of the bottom. Of the Number I or flat trials, the back left-hand one shows dishing, while the front left-hand one is straight. The two right-hand trials show a bowing up in the center.

being partly protected by the blocks carrying the flat No. 1 trials. This same general scheme was maintained throughout the four separate burns.

The method employed for the setting of No. 2 trials

was taken from the setting of the commercial Spanish tile. That is, they were set by standing them upon end on fire clay blocks, each small tile being so spaced from its neighbor that each could be free to warp or twist unrestricted, care being taken to see that each tile was standing as near plumb as possible, in order that no undue strain should be brought in.

With trials No. 3 the setting was widely different from that of Nos. 1 and 2. By referring to the cut it will be seen that the long slender trials were made to span

Fig 2.

The four trials shown represent the four heat treatments given to clay A. Starting at the back the first bar received cone 09, the second cone 07, the third cone 04 and the one in the foreground cone 01. These trials are uneven in length due to the breaking off of small pieces for the porosity determination.

across the intervening space between the two knife edges. The trials were approximately 12″ long when dry, hence the supporting knife edges were placed 10″ apart, thus allowing a 1″ over-hang of the trial on each end.

It is evident that the trials when subjected to heat would swag or bow down, depending of course upon the

viscosity of the clay. The one having a low viscosity would warp more than one of high viscosity. The knife edges had previously been prepared from fire clay, and then biscuit burned once in order that they would not crack or break while in use.

As stated before, there were two trials set in each of the four respective burns. These trials were set somewhat widely apart in order to act as checks one on the other. In no instance was there found to be anything but a very small difference in the results obtained.

Measurement of Trials.

The three sets of trials after being collected from the four burns were carefully studied to note the degree of warpage that had taken place. In each instance an endeavor has been made to express measurements in some concrete form.

Measurement of No. 1 Trials. It was assumed that these trials went into the kiln perfectly straight, so that any distortion noted after burning has been charged directly to the burning.

It was noted at once that some of the trials were straight, some dished and some bowed, instead of all being dished as had been expected. Thus in order to measure these varied conditions the following method was adopted. First a small box was selected which was wide enough to receive the tile, two shallow notches were cut in the upper face of the ends half way from side to side. A silk thread was then drawn tightly around the box from end to end at the notches, the purpose of the latter being to hold the thread at a definite place. The distance from the under side of the thread to the inside bottom of the box was carefully measured. The trials were next taken one at a time and placed in the box in such a position that the thread above exactly divided them half and half. A direct measure was now made from the under side of the thread to the upper face of tile at three points, on the two edges

and at the center, thus the dished and bowed tile as well as the straight ones were easily detected.

The figures used in the following table were obtained by subtracting the measurements taken from the thread to the top, center and edges of the tile from the total depth of box, measured as above. The differences thus found were calculated into percents of the total depth, then, by subtracting the percent obtained for the center of the tile from that of the edges, we develop a figure which represents the percent of bowing:

TABLE IX.

Results of First Warpage Experiment on Standard Roofing Tile Clays.

Cone	Designation of Clay												
	A	B	C	D	E	F	G	H	I	J	K	M	N
09..	0.00	0.00	1.04*	0.00	0.00	1.04	0.00	2.61	0.00	2.61	5.73	1.56	1.04
07..	0.00	0.00	1.05	0.00	0.00	3.13	1.56	1.04	0.00	1.04	0.00	0.00	0.00
04..	0.00	1.04	4.69	0.52	0.00	0.00	0.00	0.00	1.04	1.04	1.03*	0.00	0.52*
01..	0.00	2.08*	1.57	1.04	0.00	2.61	6.25*	1.04	2.09	7.29	8.33	1.56*	3.13*

* Trials thus marked were dished, all others were bowed.

From the above table it will be seen that a very small percent of the trials dished, as had been expected, the greater portion of them being bowed. That very little can be learned as to the warpage of a clay by this test is clearly brought out in clays A and E. From the data obtained, they would be classed as equal and perfect clays to work, while in reality clay A by the No. 3 or Cramer test is proven to be a clay of low viscosity and easily warped. It is due to no other cause or reason than its low viscosity that this clay has remained free from warpage in this test. It has remained flat or straight on account of its softness.

On the other hand, clay E has remained straight on account of its extremely high viscosity, but had this clay been carried a few cones higher it would have melted down, that is, it would have developed such a low viscosity that it would have run or spread.

Thus we see that by test No. 1 it is possible to have zero warpage from two sources, high and low viscosity. It is therefore evident that the results obtainable by such a test could be extremely misleading.

It will furthermore be noted that some of the clays have developed extraordinary results, in the fact that they have developed both dishing and bowing, and at other heats have shown no warpage. Clays G and K are examples of this. No good reason can be offered to explain why the same clay will dish at one heat and bow at another; that it may pass from either to no warpage can possibly be explained by physical chemistry. When heat is applied to a mineral mixture, a solution of the ingredients takes place; certain ones will soften earlier than others, thus tending to lower the fusing point of the mass as a whole. A point in the solution will eventually be reached, known as the eutectic, which represents the most fusible mixture of the minerals in question. Should any additions be made that would unbalance this eutectic mixture, then will the point of fusion be raised.

Assuming that the viscosity of the solution is the lowest at the eutectic mixture and, increasing on either side of this definite point, it is easy to see why clay K, for instance, has passed from high warpage at cone 09 to no warpage at cone 07; that is, the clay or mineral mixture has reached its greatest fluidity at the later cone and has, therefore, flattened or straightened out. While on either side of cone 07 the mixture has been of just the right viscosity to be drawn or warped by the heat.

Measurement of No. 2 Trials. Prior to burning, each trial of this set was carefully measured at each end. The end to be placed downward in the setting was marked, so that there might be no mistakes in the measurements after burning.

The trials when collected from the four burns were remeasured at each end. Then by subtracting the burned reading from the unburned measurement, and calculating

the results into percents of the green or unburned measure, a figure is obtained which may represent both shrinkage and warpage. By obtaining this figure for both upper and lower ends, it is only necessary to subtract one from the other to obtain the amount of warpage of one end over the other.

In the following table will be found the figures for both upper and lower ends of each trial at the four burns, and a column of differences which should represent the percent warpage.

TABLE X.

Results of Second Warpage Experiment on the Standard Roofing Tile Clays.

Designation of Clay	Cone 09			Cone 07		
	Percent contraction upper end of tile.	Percent contraction lower end of tile.	Difference	Percent contraction upper end of tile.	Percent contraction lower end of tile.	Difference
A	1.59	1.59	0.00	2.63	1.82	0.81
B	0.68*	0.139*	0.541	0.83	0.27*	1.10
C	0.972	0.110	0.862	3.01	2.31	0.70
D	0.481	0.278	0.203	0.27*	0.69*	0.42†
E	0.744	0.604	0.104	0.59	0.89	0.30†
F	1.25	1.06	0.19	1.09	1.91	0.82†
G	0.55	0.41	0.14	1.32	1.87	0.55†
H	0.291	0.298	0.007†	2.36*	2.21	4.57
I	0.41*	0.55	0.96	0.70*	0.27	0.97
J	3.35	4.58	1.23†	1.54	1.12	0.42
K	3.38	2.54	0.84	5.15	1.77	4.38
M	.....	.....	.....	0.82	0.13	0.69
N	5.20*	5.28*	0.08†	3.43	3.83	0.40†

* Expansion, instead of contraction.

† Percent that bottoms have contracted in excess of the tops.

TABLE X—Continued.

Designation of Clay	Cone 04			Cone 01			Average
	Percent contraction upper end of tile.	Percent contraction lower end of tile.	Difference	Percent contraction upper end of tile.	Percent contraction lower end of tile.	Difference	
A	8.13	6.57	1.56	9.41	4.48	4.93	1.82
B	2.06	1.51	0.55	3.90	3.01	0.89	0.512
C	16.32	12.06	4.26	9.27	9.33	0.06†	1.470
D	8.31	2.84	5.47	1.75	1.62	0.13	1.55
E	0.86	0.714	0.146	4.83	3.94	0.89	0.038
F	3.71	1.65	2.06	7.92	6.52	1.40	1.117
G	6.07	4.84	1.20	4.41	0.666	3.75	1.41
H	0.00	0.16*	1.16	3.91	3.24	0.67	1.60
I	1.25	1.67	0.42†	2.13	1.43	1.70	1.01
J	16.94	15.05	0.89	0.43	5.78	5.35†	1.97
K	1.30	2.32	1.02†	13.46	7.91	5.55	2.94
M	0.82	1.54	0.72†	5.79	0.41	5.38	2.26
N	1.16	0.57	0.59	0.54	0.24	0.30	0.34

* Expansion, instead of contraction.

† Percent that the bottoms have contracted in excess of the tops.

While these trials have, in a general way, marked the high warping clays, such as A, J, K and M, at cone 01, the results for other clays at this cone do not properly class them according to the No. 3 or Cramer test. Again the results from cone to cone for many of the clays are not consistent; for instance, clay C at cone 04 shows a warpage of 4.26 percent, while at cone 01 the warpage was only .06 percent, where it should be about the same as A. Again, clay H shows very much the same condition. In explanation of these irregularities it is quite possible that much of the trouble has come from personal factor in the making of these trial pieces by hand, and again, they should have been made larger and with a thicker cross section than $\frac{1}{4}''$, many of them failing by having the central portion of the tile bulge out, while the ends retained their shape.

In order to make this test of value, the trials should be larger and, above all, should be expressed through a die, rather than attempting to mold them by hand.

In a comparison of the fire shrinkage and warpage, it is very clear from the behavior of clays K and C in this

method of testing, that there is no relation between the numerical values of the properties in different clays. Clay K has a fire shrinkage at cone 01 of about 9 percent and has shown a warpage of 2.94 percent. Clay C at cone 01 shrinks in the neighborhod of 8 percent, and only shows a warpage of 1.47 percent, or just one-half that of K.

Clays C, D, G, H and I show similar warpage in the above test, and these same clays have fallen quite closely together in the other two tests for warpage as well. Clays M and B give erratic results in this test. It is believed, in the light of the third warpage test, that the figures for these clays are not representative, and that B and M should be classed with clays like C and D, while B, as here shown, belongs with clays E and N, and M with K. Clays E and N show a very low degree of warpage, but their high lime content, their slow vitrification, that is, high porosity until nearly ready to fuse, and the suddenness of their fusion when it once begins, all show that their behavior would not be like the easy vitrifying clays composing the rest of the series.

Measurement of No. 3 Trials. In these trials, as with No. 1, it was assumed that they went into the kiln with no warpage, so that their measurement has only been made upon the burned pieces.

In order to make the measurements a thin rubber band was stretched from end to end of the trial across the intervening space, as indicated by the dotted lines in Fig. 3.

A direct measure was then made from the under side of the rubber band to the upper face of trial. This figure should represent the real warpage of the clay at any heat treatment.

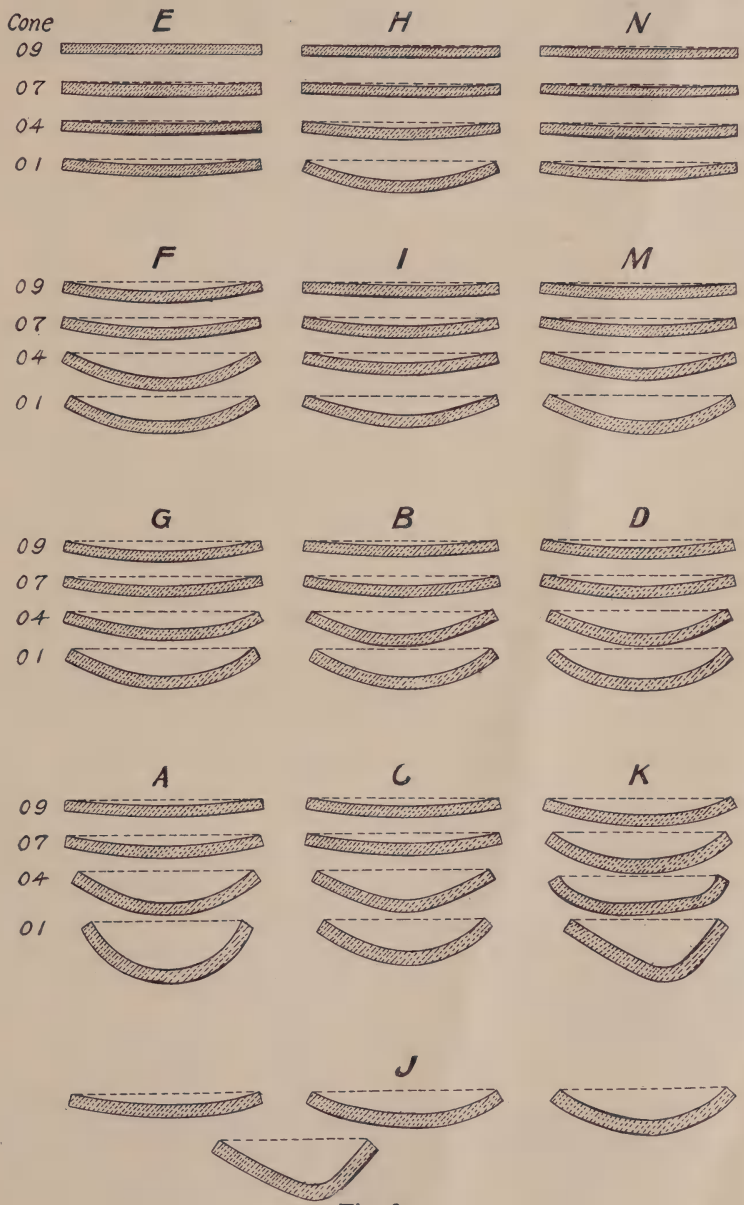


Fig. 3.

The following table lists the different deformations at the four heat treatments given to the trials. The figures given are the average of two trials in each case.

TABLE XI.

Deformation under Heat.

Clay	Cone 09	Cone 07	Cone 04	Cone 01
A	5.27	11.80	38.02	47.15
B	5.57	12.55	29.50	42.00
C	5.95	10.92	36.35	47.15
D	7.47	10.87	21.82	41.30
E	0.00	1.80	2.47	8.60
F	8.10	11.22	24.95	41.55
G	8.50	11.12	32.15	41.55
H	1.87	3.02	8.27	24.80
I	5.87	12.00	15.02	25.30
J	8.40	20.10	35.50	61.15
K	17.75	37.95	38.30	62.00
M	6.10	10.15	19.25	40.50
N	1.32	1.62	4.55	5.75

That the shrinkage of a clay is a poor criterion to judge warpage by is clearly shown by a comparison of these two properties in a number of the clays tested. By examining table IV it is found that the drying shrinkage of clay H is the highest, 7.5 percent, while clay G has the lowest, 2.06 percent. Their warpage behavior, from table XI, shows that clay G at cone 04 has a warpage nearly four times greater than does clay H. With the shrinkage data only to judge by the usual or general classification would have been to place clay H in the highly warping class and clay G in the opposite. This same thing is true of other clays, for instance, clays A and E. From such conditions there can be no question but that warpage is an inherent property of any given clay, and does not admit of judging the behavior of one clay by that of another.

Fire shrinkage does, however, in a general way, follow closely with warpage, though this is not true in all cases. By table XI, which gives the fire shrinkage as well as the

warpage, it is apparent that clays A, C, J and K have a relatively high fire shrinkage, and at the same time develop a high warpage. On the other hand, clay H has a high fire shrinkage when compared with clay I. The latter clay at cone 04, however, develops a warpage about twice as great as does clay H. The same thing can be seen in clays M and N.

As stated before, in mention of the work done by Day and Allen, complete vitrification is not always followed by deformation. That this statement is true or, in other words, that low porosity is not always followed by high warpage, is clearly derived from table XI. Clays D and M at cone 01 have a porosity of 23.01 and 22.26 percent respectively. Their warpage is as great as other clays which show a porosity of only 10 to 12 percent. Again, two clays may have widely different percents of porosity and still have approximately the same degree of warpage. This is clearly shown in clays D and G, also in clays B and M.

In most cases low porosity is a mark of high warpage, which is the natural thing to expect.

In order to more easily study the above relation, table XII has been prepared which shows the percents fire shrinkage, porosity and warpage at the four heat treatments:

TABLE XII.

Results of the Third Warping Test on the Standard Roofing Tile Clays, with Results of Fire Shrinkage and Porosity Tests Added for Comparison.

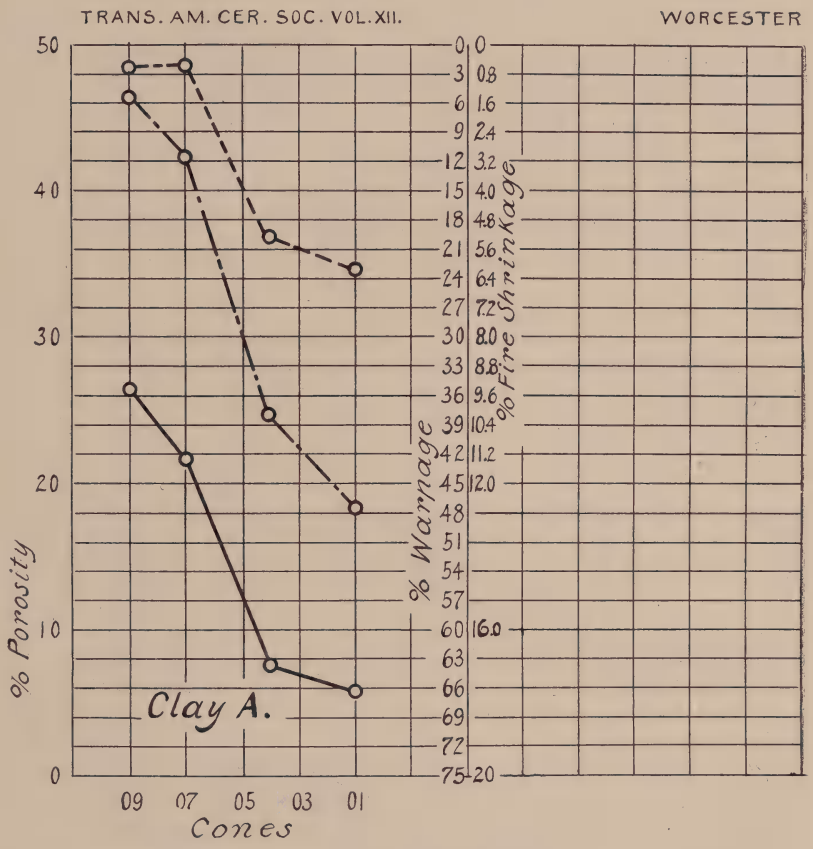
Designation of Clay	Cone 09			Cone 07		
	Percent Fire Shrinkage	Percent Porosity	Measure of Warpage	Percent Fire Shrinkage	Percent Porosity	Measure of Warpage
A	0.55*	26.49	5.27	0.55	21.71	11.80
B	0.12	26.24	5.57	0.87	19.26	12.55
C	0.45	32.72	5.95	1.25	28.44	10.92
D	0.05*	31.79	7.47	0.10	32.20	10.87
E	0.20*	39.54	0.00	0.30*	29.01	1.80
F	0.55*	31.05	8.10	0.05	30.11	11.22
G	1.00	25.28	8.50	2.87	23.83	11.12
H	0.20*	31.03	1.87	0.10	30.35	3.02
I	0.50	30.07	5.87	0.50	29.90	12.00
J	1.50	16.81	8.40	3.00	10.56	20.10
K	3.24	16.27	17.75	5.19	10.19	37.95
M	0.25*	30.96	6.10	0.55	28.03	10.15
N	0.00	36.32	1.32	0.00	36.13	1.62
	Cone 04			Cone 01		
A	5.15	7.57	38.02	6.10	5.75	47.15
B	2.00	11.81	29.50	2.25	11.74	42.00
C	6.00	11.86	36.75	7.20	8.81	47.15
D	3.50	28.74	21.82	5.62	23.01	41.30
E	0.20	38.34	2.47	2.20	34.88	8.60
F	3.35	22.42	24.95	4.52	18.91	41.55
G	4.50	12.75	32.15	5.25	10.70	41.55
H	1.70	29.20	8.27	2.90	26.02	24.80
I	0.50	31.29	15.02	0.62	25.13	25.40
J	5.50	2.99	35.50	5.75	2.82	61.15
K	7.79	6.65	37.30	5.89	2.78	62.00
M	1.55	25.73	29.25	2.42	22.26	40.50
N	0.50	37.91	4.55	1.50	7.57	5.75

* Increase above original dry length.

The data in table XII has been plotted in the following curve sheets. For convenience in observing the fact, the warpage and fire shrinkage are made to read down the page, while the porosity reads up. By this expedient, all the curves are made to traverse the paper in the same direction. Also, the scale selected for each kind of data is different, and is chosen to make the curves change eleva-

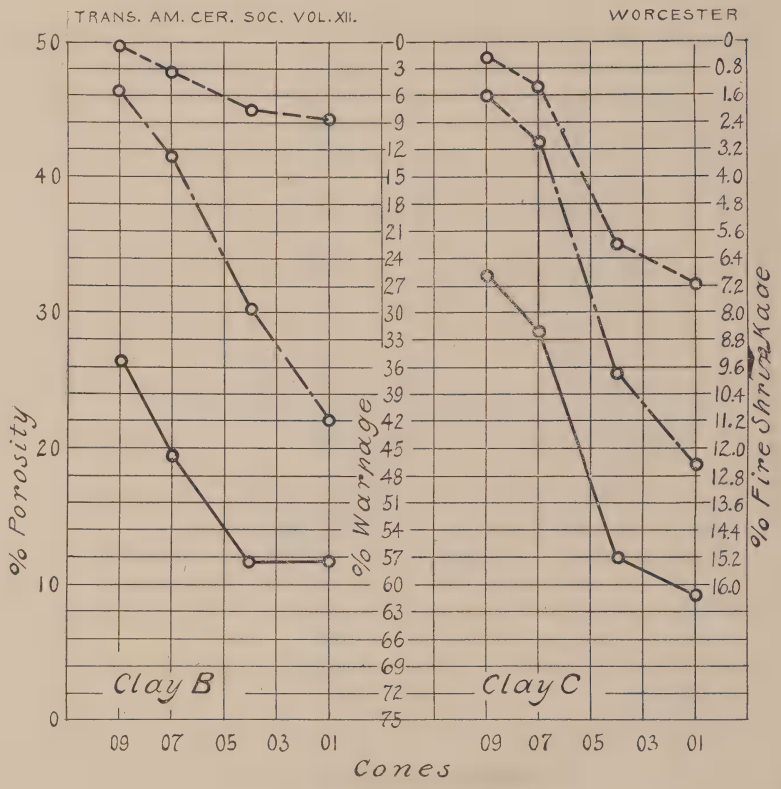
tion at about the same rate in the average case. If one property changes faster than another the curves immediately lose parallel.

A careful study of these curves reveals the close rela-



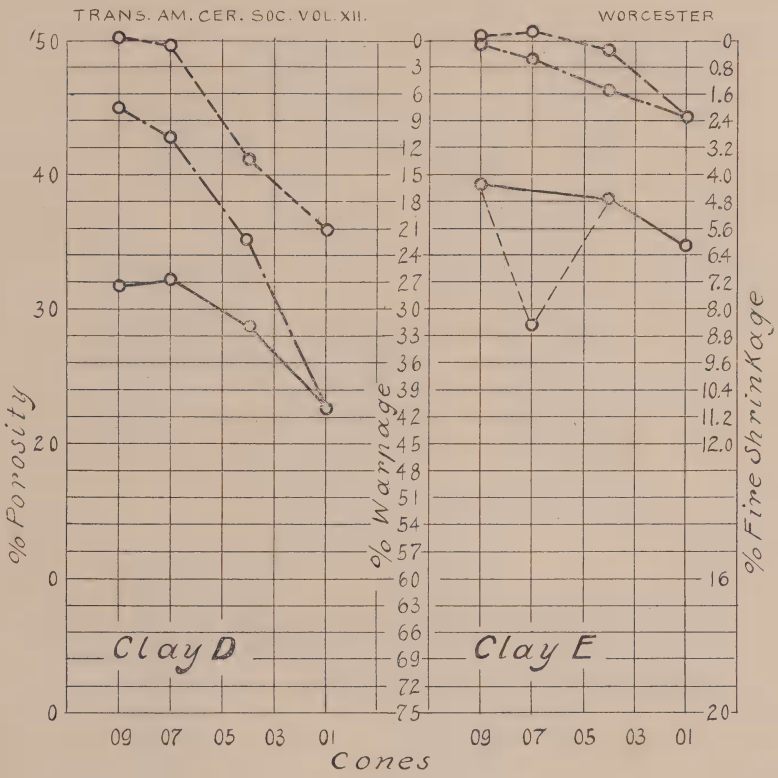
tion which exists between the changes of volume and the changes of form. This is as has been assumed and expected, but up till the present no proof had been submitted, so far as known.

There are, however, some puzzling inconsistencies in the data. These inconsistencies may come from the fact that we are dealing with a very small number of trial pieces.



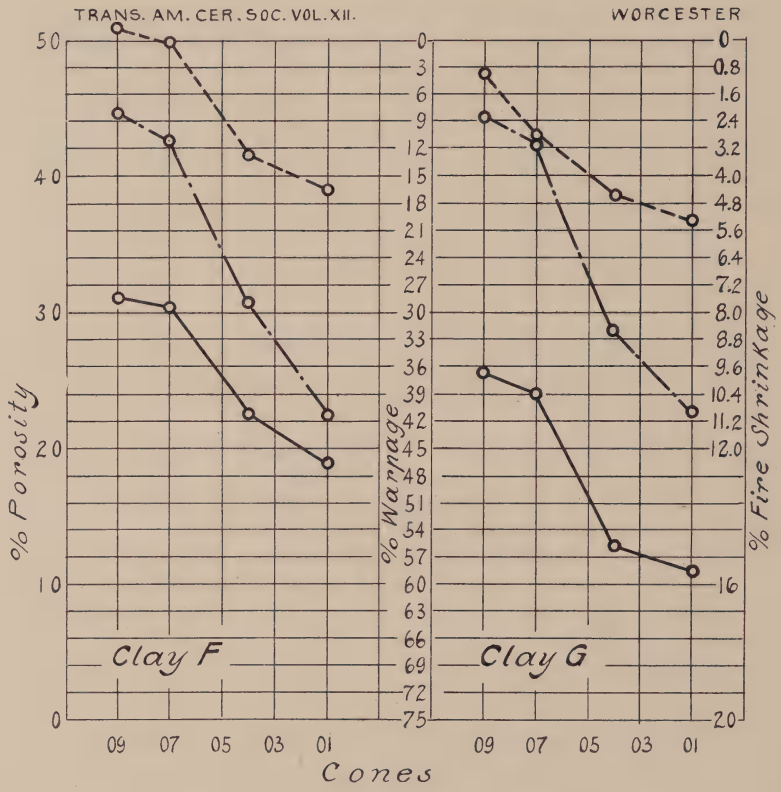
The three kinds of curves in clays A, C, E, G and H show a marked concurrence in direction and rate of change. Clays A, C and G are clays which shrink rather highly, decrease in porosity rather sharply, and warp rather evenly, but in considerable amount. Clays E and N are calcareous, and do not reach their active vitrification process in the temperature zone studied, and therefore, show but

very little shrinkage and warpage, nor does their porosity decrease. Thus they enter but very little in this discussion.



In the clays D, F, H, J, K and M there is again a marked concurrence between the rates of fire shrinkage, porosity extinction, and warpage, especialy at cones 09, 07 and 04, but between cones 04 and 01 the warpage changes faster than the other properties do. This should be expected, if we consider warpage as being the result of incipient fusion of the clay—the development of a viscous taffy-like material in the clay body. As the heat increases

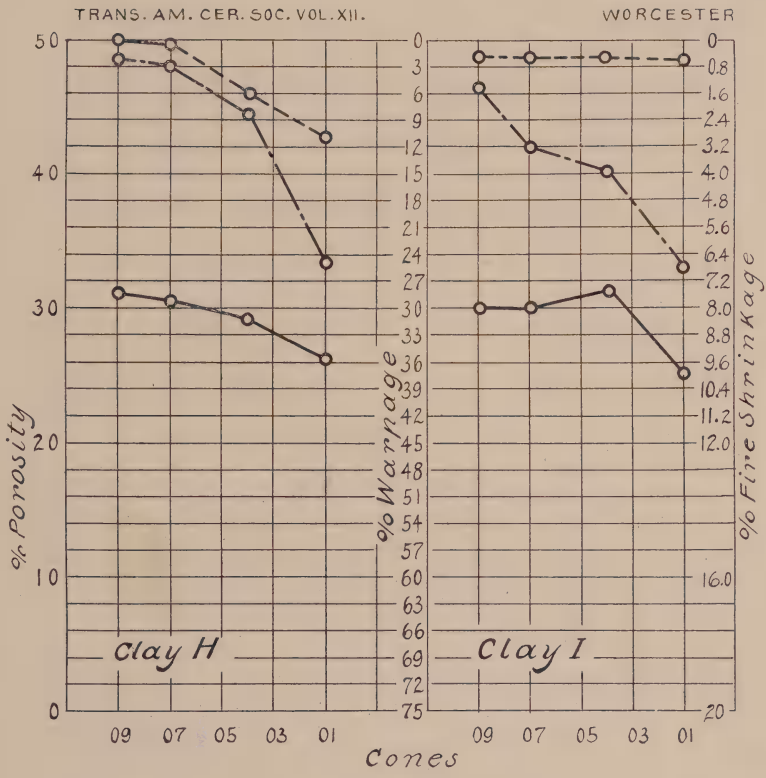
the amount and fluidity of the viscous material raises as a rule. This condition has probably existed in the above clays.



In two clays of the thirteen examined, viz., B and I, we find the situation less easily read. B is remarkable for its low shrinkage, while its porosity curve and warpage behavior are concordant with the larger number of samples tested.

In clay I the curves indicate that the vitrification process was quiescent up to cone 04, neither fire shrinkage nor reduction of the porosity occurring. At the same time

low warpage took place. At cone 04, porosity suddenly decreased, concurrent with warpage, but the shrinkage was still unaffected.

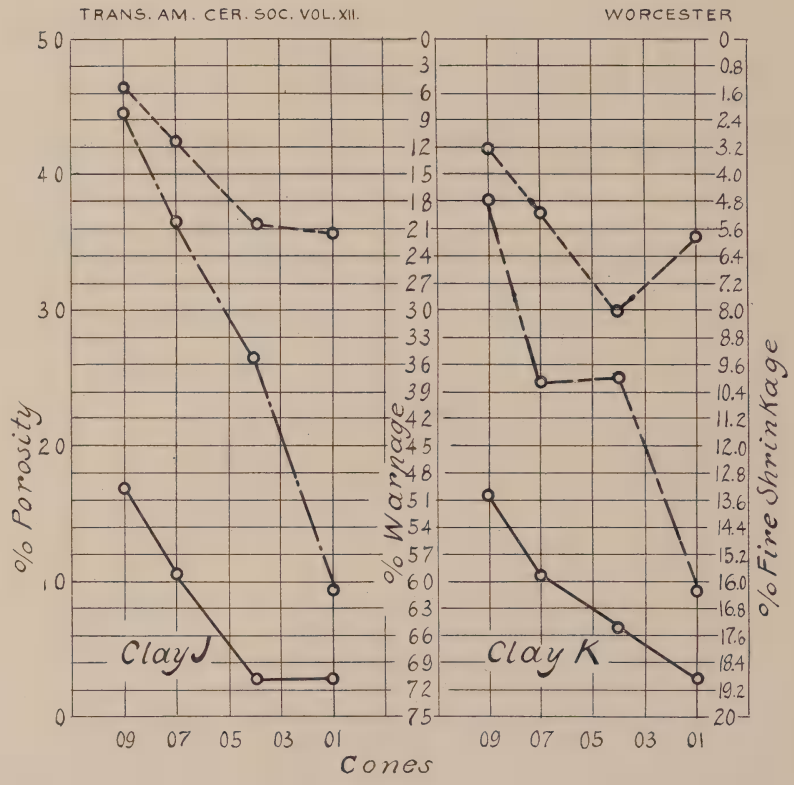


GENERAL DEDUCTIONS.

1st. Change of shape in the burning of a clay ware is a function of the vitrification process, and results from the formation of a viscous silicate matrix, while the principal part or skeleton of the clay is still solid.

2nd. The changes of shape which occur early in the burn, while the clay ware still retains its general shape

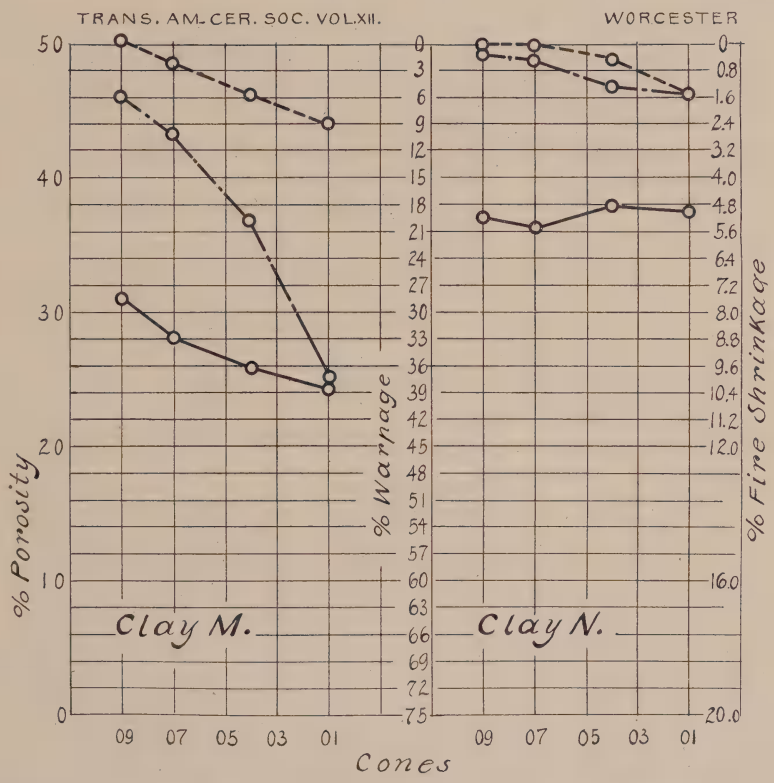
and usefulness, and those late changes from over-fire which destroy the shape for commercial uses, are stages of one and the same process.



3rd. The rate of change of shape in normal clays is closely parallel to the rate of the other vitrification changes (shrinkage, porosity, etc.), for a time, but as the rate of shrinkage and porosity changes decreases on approaching completion, the rate of change of shape increases.

4th. The tendency to warpage and the absolute amount or numerical value of the warpage of a clay at any given temperature is an inherent property of the material,

and does not admit of prophecy, i. e., knowledge of the behavior of one clay does not justify us in assuming what the next clay will do. Warpage stands on the same plane in this respect as the other properties of a clay. Nor can



warpage be correlated at all closely in numerical amounts with the shrinkage, porosity, or other properties of the clay. For instance, two clays of equal warpage may not agree closely in shrinkage or porosity. Likewise, clays having the same shrinkage or porosity, may or may not have similar warpage. Also, while high shrinkage and low porosity incline us to expect high warpage, it does not always follow. The relation is only a general one.

5th. In estimating the value of clays for roofing tile purposes, or any use where thin-section wares are made, the determination of the warpage tendency is a practical test, second in importanec only to color and vitrification range.

In conclusion I wish to state that I am greatly indebted to Prof. Edward Orton, Jr., for his valuable assistance in this study, the presentation of the data obtained, and the conclusions drawn therefrom.

I furthermore wish to express my thanks to Dr. J. A. Bownocker, State Geologist of Ohio, for his permission to present this paper in advance of its publication as a part of a bulletin on the roofing tile industry, in course of preparation for the Ohio Geological Survey.

DISCUSSION.

Mr. Child: I would like to ask Mr. Worcester if he did not find that the deflection was always at the top of the kiln instead of at the bottom?

Mr. Worcester: I might have explained that a little more fully. It is not customary to set one tile upon the other. We set up boxes or pigeon-holes of fireclay blocks and our tiles are set in those boxes so that each one stands separate from the other. There are quite a number of the plants, at least three of them, that are setting their tile one upon the other, but they dare not approach vitrification.

Mr. Child: In that case where they set one over the other, would not that do away with the point which you just brought out a few minutes ago?

Mr. Worcester: Well, that might possibly be so, but the time that it would take to get our tile so perfectly placed one over the other would make it impracticable.

Mr. Lovejoy: In setting the tile is it not customary to put strips of clay under the tile and on top of them?

Mr. Worcester: It has been found that Spanish tile

can be prevented from warping to a large extent by a trick of the trade, so to speak. When the tile are set in the kiln boxes or saggers they are stood upon a green or plastic blank ½″ thick of the same material as the tile. In fact, the tile are pressed down into the plastic blank, in order that the tile may be braced or held to their correct shape.

When the sagger has been filled with the tile, three 1″ strips are cut from a green blank. These narrow strips are then distributed over the top end of the tile and lightly spatted down with a trowel. Thus the upper ends of the tile are braced or retained in the same manner as the lower. The shrinkage of the green blank seems to be just sufficient to hold the tile true to shape.

Mr. Gorsline: I was just about to say, Mr. Worcester, that you might well do as we do in setting sewer pipe, provide a ring, etc., set the tile on and throw away the ring each time after burning.

Mr. Worcester: Spanish tile are more difficult to burn than pipe for the reason that their shape is such that there is practically no support at all. They are nothing but a thin webbing of clay, while the conduit is circular and self supporting. The strips are the best means found so far.

Mr. Gorsline: In such cases you could run them out double from the die and break them apart after burning. This permits the tile to retain its form. Such tile can be set in kiln with less care and loss and will not be as liable to warp.

Mr. Worcester: In a few instances the tile are run out double, like a pipe, then after burning they are broken apart. This method does prevent quite a good deal of the warpage, but there are other serious drawbacks to it.

Mr. Hamilton: In overcoming that trouble with fire clay I might add that we use the ordinary silica sand exclusively. They are set down on end and the bottom does not crack. We used the silica sand and that seemed to

overcome that trouble and allowed the bottom to get its proper shrinkage along with the top.

Mr. Worcester: Well, that would do too, in some clays, but in other clays where there is low viscosity, as we call it, that is the weight of the tile standing on end, would not hold as it would where they are bedded in the green strips. A clay of low viscosity would have a tendency either to spread or pull in.

Mr. Lovejoy: My objection to the use of sand is that it has an effect on the color, which will be different on that part of the tile buried in the sand.

Mr. Reis: Mr. Worcester are you at liberty to state whether any of these clays were calcareous?

Mr. Worcester: Clays E and N are both calcareous.

Mr. Reis: Have you tried any magnesia clays in Wisconsin?

Mr. Worcester: No. We might find some very interesting facts if we did.

Mr. Yates: The underlying secret, as I understand it through experience in making very thin tile is to take short clays with little shrinkage, say one-half inch to the foot or less, grind it fine and weather it for bond. The clay should stand a high temperature, sufficient to vitrify and at the same time hold its shape.

Mr. Worcester: The high shrinkage clays do not always show a high deformation in the burning. Some of them shrink twice as much as others and yet have a lower deformation. The burning shrinkage does show some relation to deformation.

I really do not think that the developing of plasticity or the weathering of the clay has much to do with the deformation of it. It is purely a mineralogical condition. We could get greater warpage in the drying by developing a greater plasticity in a given clay.

Mr. Yates: I can take you to a kiln of these roofing tiles that is made of old weathered stock at Peak's Tileries, Tunstall, Staffordshire, England, and you will find that

the finish of the ware from this clay is as smooth as a kid glove, while the same tile made from raw stock, that is unweathered clays, will have a finish as rough as sand paper, with considerable loss in burning, and the tiles will be of inferior quality as compared with clays that have been weathered for years.

Mr. Parker: Do you mean by deformation the warpage or shrinkage due from excessive heat?

Mr. Worcester: I wish to call your attention to these two samples upon which I rely for my statement, one is vitrified and the other porous, both are warped badly. As stated before, warpage is due to the viscosity of a clay while under heat treatment.

In answer to Mr. Yates, there is only one roofing tile plant in the United States weathering their clays, that is, getting them out one year and using them the next. Their explanation for doing this is that if you use them direct from the bank you get a greater percentage of cracked tile. By weathering the clay they get greater strength and less kiln checked tile in the burning of them.

Mr. Knote: To explain the behavior of clay F, I would like to say that in some work we have done we find that just below cone 010 a great deal of chemical and physical activity takes place. There is a constant specific gravity change there which gives the clay more or less of a sudden strain, different with different clays. In pure clay we find it to be quite constant. I am not at all surprised, after what I have found, to see the chart which Mr. Worcester has given us there. That is, that the warpage does take place at about that temperature where we had supposed there was not much chemical activity.

Mr. Stolp: I have followed the interesting paper of Mr. Worcester very carefully and he comes to the same conclusion that is shown in practice, that different clays will twist or warp to a different degree in the same heat.

In judging this difficulty, in the manufacturing of roofing tile, you must take into consideration that there

are two distinct types of roofing tiles, the vitrified and the non-vitrified. The first named is a special American type. The second is made and used all over Europe. There is a distinct difference in the manufacture of each kind.

The shrinkage of clay is necessary in most clay products, but especially in roofing tile, because it must have a close, compact body to shed water. The shrinkage of the non-vitrified tile is in drying and of the vitrified tile in burning. To prevent warping and cracking of the tile in drying you must dry slow, if it proves that quick drying is harmful. To prevent warping in vitrification you have to depend on all kinds of tricks in the trade, and those tricks are of the kind that sometimes help and are sometimes useless.

The effect of the use of the auger machine is to create laminations or cavities where water collects, and the freezing of the water results in disintegration of the tile. The non-vitrified tile is made of a plastic clay or shale, preferably weathered and by the soft mud process, so as to counteract as much as possible the laminations of the auger machine. The tile are afterward burned as hard as the clay will stand without warping.

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